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WARTIME REPORT

WIND-TUNNEL TESTS OF SPOILERS ON TAIL SURFACES

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ADVANCE RESTRICTED REPORT

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SUMMARY

Wind-tunnel tests have been made in two-dimensional and three-dimensional flow to investigate the aerodynamic characteristics of spoilers on tail surfaces for low-speed flight.

The test results indicated that spoilers on tail surfaces showed little possibility of replacing conventional control surfaces. Spoilers might be used as auxiliary aids to conventional control surfaces if a number of the disadvantages that they present can be remedied or tolerated. These disadvantages consisted principally of high drag, erratic action, and an adverse effect on normal control-surface hinge moments.

A spoiler on the forward portion of the tail surface, used alone or in conjunction with the conventional control surface, gave unsatisfactory results because of its erratic effect throughout the angle-of-attack range. Spoilers generally should be located on the rear portion of the tail surface, but an auxiliary forward spoiler might be advantageous in depressing the tail in the landing maneuver. A forward auxiliary spoiler should be located on the opposite side of the tail surface from the rear spoiler, since two spoilers on the same side of the tail surface tend to cancel the effects obtained by the use of either spoiler alone.

INTRODUCTION

A number of modern airplanes have encountered difficulty in landing because of inadequate elevator control. Very large control deflections are required

for landing because of the marked increase in longitudinal stability that results from the proximity of the ground. The large elevator deflections required to attain the landing attitude cause the mechanical advantage of the control system to be low and the elevator hinge-moment coefficients to be high. These two factors result in high stick forces at both high and low speeds. Often the control forces necessary to trim the asymmetric yawing moments on single-engine airplanes with single-rotating propellers and on multiengine airplanes with asymmetric power are also excessive. In many cases the rudder effectiveness is insufficient even if the control forces are small.

It has been suggested that spoilers might be used as supplementary or auxiliary controls to reduce some of the control difficulties just mentioned. Tests have consequently been made at various times in the Langley 7- by 10-foot tunnel of spoiler-elevator controls on three complete airplane models. An NACA 0009 airfoil with various spoilers and combinations of spoilers also was tested in two-dimensional flow in the Langley 4- by 6-foot vertical tunnel.

The purpose of the present report is to collect, summarize, and analyze the data that have been obtained on the application of spoilers to tail surfaces for the critical control condition at low speed.

SYMBOLS AND CORRECTIONS

Symbols used for tests in two-dimensional flow are as follows:

c_l airfoil section lift coefficient $\left(\dfrac{l}{qc}\right)$

c_{d_o} airfoil section profile-drag coefficient $\left(\dfrac{d_o}{qc}\right)$

c_m airfoil section pitching-moment coefficient $\left(\dfrac{m}{qc^2}\right)$

c_{h_f} flap section hinge-moment coefficient $\left(\dfrac{h_f}{qc_f{}^2}\right)$

c_{h_t} tab section hinge-moment coefficient $\left(\dfrac{h_t}{qc_t{}^2}\right)$

l airfoil section lift, pounds

d_o airfoil section profile drag, pounds

m airfoil section pitching moment, foot-pounds

h_f flap section hinge moment, foot-pounds

h_t tab section hinge moment, foot-pounds

q dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

c chord of airfoil section (2 ft)

c_f flap chord, feet

c_t tab chord, feet

a_o angle of attack for infinite aspect ratio

δ_f deflection of flap with respect to airfoil, degrees; positive when trailing edge is moved down

δ_t deflection of tab with respect to flap, degrees; positive when trailing edge is moved down

ρ mass density of air, slug per cubic foot

V air velocity, feet per second

     Symbols used for tests in three-dimensional flow are as follows:

C_L lift coefficient $\left(\frac{L}{qS}\right)$

C_{D_R} resultant-drag coefficient $\left(\frac{D}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{M}{qSc}\right)$

C_{h_e} elevator hinge-moment coefficient $\left(\frac{H_e}{qb_e \bar{c}_e{}^2}\right)$

D resultant drag, pounds

L lift, pounds

M pitching moment, foot-pounds

H_e elevator hinge moment, foot-pounds

q dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

S wing area (9.44 sq ft for model A; 6.65 sq ft for model B)

c' wing mean aerodynamic chord (1.36 ft for model A; 1.07 ft for model B)

b_e span of elevator (2.50 ft for model A; 2.79 ft for model B)

$\overline{c_e}$ root-mean-square chord of elevator behind hinge line (0.199 ft for model A; 0.160 ft for model B)

α angle of attack of fuselage reference line, degrees

δ_e elevator deflection, degrees; positive when trailing edge is moved down

δ_r deflection of rudder with respect to fin, degrees; positive when trailing edge is moved to left

δ_f flap deflection, degrees; positive when trailing edge is moved down

i_t angle of stabilizer with respect to fuselage reference line, degrees; positive when trailing edge is moved down

ρ mass density of air, slug per cubic foot

V air velocity, feet per second

ψ angle of yaw

$c_{t_{av}}$ average chord of horizontal tail (0.687 ft for model A)

c_t chord of horizontal tail at any point along span

c_s height or chord of spoiler; expressed in fraction of $c_{t_{av}}$ for model A and c_t for model B

δ_s projection of spoiler measured perpendicularly from top edge of spoiler to surface of tail; positive when spoiler projects from lower surface and negative when spoiler projects from upper surface; expressed in fraction of $c_{t_{av}}$ for model A and c_t for model B

Subscripts:

F   forward

R   rear

Tunnel corrections were applied to the airfoil section lift coefficient c_l as explained in reference 1. No corrections were applied to the airfoil section pitching-moment coefficient c_m or to the airfoil section profile-drag coefficient c_{d_o}, although the values of c_{d_o} presented may be too large as explained in reference 1. The angle of attack was not corrected, but this correction would be quite small.

APPARATUS, MODELS, AND TESTS

Two-Dimensional Flow

The section data presented herein were obtained from tests made in the Langley 4- by 6-foot vertical tunnel (reference 2) modified as discussed in reference 3. The 2-foot-chord by 4-foot-span model was made of laminated mahogany and conformed to the NACA 0009 profile. The airfoil profile with spoilers in forward and rear locations is shown in figure 1. The model had an enclosed hinge-moment balance for measuring the hinge moments of the 0.30c plain flap. The spoilers were made of sheet steel 1/32 inch thick, had spans of 4 feet, and were projected 0.01c, 0.03c, 0.06c, and 0.09c at the forward location and 0.01c, 0.025c, 0.05c, 0.10c, and 0.15c at the rear location. The spoilers were screwed to the model at right angles to the surface, and strips of cellulose "scotch" tape were used to prevent air flow under the spoilers.

The tests were made at an average dynamic pressure of 15 pounds per square foot, which corresponds to a velocity of 76 miles per hour under standard conditions. The test Reynolds number was 1,430,000, and the effective Reynolds number was 2,765,000 based on a turbulence factor of 1.93 for the Langley 4- by 6-foot vertical tunnel. A résumé of the tests in two-dimensional flow is given in table I.

Three-Dimensional Flow

Three low-wing complete airplane models were tested
in the Langley 7- by 10-foot tunnel, which is described
in reference 1. Tests were made of a model of a single-
engine fighter airplane with single-rotating propeller,
which is referred to herein as "model A." Other tests
were made of a single-engine bomber-torpedo model with
dual-rotating propeller, which is referred to herein
as "model B." A few tests were made of a third com-
plete model of a typical fighter airplane to find the
effects of elevator nose gap on the characteristics of
a tail with a spoiler.

The ground was simulated by a flat wooden board
extending completely across the tunnel and several feet
ahead of and behind the model. A complete description
of this ground board is given in reference 4. The
ground board was adjusted so that it was almost tangent
to the front wheels of the landing gear at an angle of
attack of 0° - the wheels actually never made contact
with the ground board.

Model A.- A three-view drawing of model A is shown
in figure 2. When the model was set at the angle of
attack for maximum lift coefficient (15°), the landing
gear was about $1\frac{1}{2}$ inches above the ground board.

The spoilers had spans of 73 percent of the
horizontal-tail span and were made in two sections,
which were mounted symmetrically on each half of the
horizontal tail. Single spoilers with chords of 0.06,
0.09, 0.15, and 0.25 of the average tail chord were
tested. For most of the tests, the spoilers were mounted
parallel to the trailing edge of the tail at 67.7 percent
of the average tail chord (fig. 3(a)). A few tests were
made with combinations of two spoilers mounted as shown
in figure 3(b).

All tests of model A were made at a dynamic pressure
of 4.09 pounds per square foot, which corresponds to a
velocity of about 40 miles per hour and to a test Reynolds
number of about 497,000 based on a mean aerodynamic chord
of the model wing of 16.32 inches. The effective
Reynolds number was about 795,000 based on a turbulence
factor of 1.6 for the Langley 7- by 10-foot tunnel. All
tests were made with the propeller windmilling.

Tests were made with spoilers of several chords, for which the spoiler projection was equal to the chord. As a basis for comparison, tests were made with the model near the ground board, the split flaps neutral or deflected 45°, and elevator deflections (plain elevator with gap sealed) ranging from 0° to -45°. A few tests were made with a fixed-chord spoiler at projections that introduced a gap between the spoiler and the upper surface of the tail. Combinations of spoilers were also tested on the upper and the lower surfaces of the tail. A résumé of the tests of model A is given in table II.

Model B.- A three-view drawing of model B is shown in figure 4, and a diagram of the model mounted near the ground board is shown in figure 5. The horizontal tail (fig. 6(a)) was tested in the normal location or raised 4.0 inches as shown in figure 6(b). The vertical tail was removed for all tests with the raised horizontal tail, since data not presented show that the vertical tail has no effect on the longitudinal stability characteristics.

The dimensions and location of the spoilers tested on the horizontal tail are shown in figure 6(a). Since the tail thickness at the station at which the spoilers were located was 0.10 of the tail chord, this thickness determined the maximum spoiler projection that could be retracted into the tail perpendicular to the chord line. In addition to the spoilers of maximum height, spoilers of $0.01c_t$, $0.025c_t$, and $0.05c_t$ were tested. The spoilers were constructed of steel plate 1/32 inch thick and were fastened to the tail surface by means of small metal angles.

All tests of model B were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of about 80 miles per hour and to a test Reynolds number of about 800,000 based on the wing mean aerodynamic chord of 12.81 inches. The effective Reynolds number was about 1,280,000 based on the turbulence factor of 1.6. All tests were made with the propeller windmilling and with the model in the landing configuration, which is defined as follows:

Inboard-flap deflection, δ_{f_i}, deg. 50

Outboard-flap (balanced split) deflection, δ_{f_o}, deg 50

Cowl-flaps deflection, δ_{f_c}, deg 25

Landing gear and slats . . . . Extended

Tests were made with elevator alone and with spoiler projections of $0.01c_t$, $0.025c_t$, $0.05c_t$, and $0.10c_t$ for the horizontal tail in its normal location. Elevator tests without a spoiler and with a spoiler projection of $0.10c_t$ were made for the horizontal tail in its raised location. A résumé of tests of model B is given in table III.

Elevator gap.- A drawing of the horizontal tail and a $0.008c_t$ spoiler on the model tested to find the effect of sealing the elevator gap is shown in figure 7. Four tests were made with the nose gap sealed or unsealed and with or without a spoiler.

Elevator deflection required to land.- Some data on the elevator deflection required to land were compiled for various fighter models tested in the Langley 7- by 10-foot tunnel. These models were tested near a ground board, and the data are presented in figure 8.

All of the data from tests in three-dimensional flow, except those for model A with flaps retracted, are uncorrected for tares due to the model support. No corrections for tunnel-wall effect have been applied, since reference 4 indicates that the tunnel correction for the ground-board test installation is negligible. All forces and moments for models A and B are given with respect to the wind axes of the models; center-of-gravity locations shown in figures 2 and 5 are used.

RESULTS AND DISCUSSION

Two-Dimensional Flow

The results of the tests in two-dimensional flow are given as airfoil aerodynamic section characteristics in figures 9 to 16. For the purpose of showing the effectiveness of the various arrangements, increments of section lift coefficient and flap section hinge-moment coefficient are plotted against flap deflection and spoiler projection in figures 17 to 26.

Flap alone.- The curves of figure 9 show the effect of flap deflection on the aerodynamic section characteristics of the plain airfoil. Increments of lift and hinge-moment coefficients produced by flap deflection

obtained from figure 9 for various angles of attack are
presented in figure 17. These curves are a basis for
the comparison of the effectiveness of various combina-
tions of spoilers or of spoilers and flaps.

For the landing maneuver, a -30° deflection of a
0.30c flap is usually sufficient for a conventional
fighter airplane. The angle of attack of the tail is
approximately 8° in landing. A flap deflection of -30°
was not tested but, for a flap deflection of 30° and an
angle of attack of -8° (reference 5), which can be used
since the airfoil is symmetrical, the data of figure 17
indicate that the increment of airfoil section lift
coefficient would be about -1.07. Any satisfactory
arrangement of spoiler or of spoiler and flap therefore
should develop about this increment of airfoil section
lift coefficient.

Rear spoiler alone.- A rear spoiler alone on the
upper or lower surface appears to be usable as a control
device (figs. 10 and 13) except for its ineffectiveness
in producing changes in lift at low spoiler projections.
This ineffectiveness apparently occurs at all angles of
attack within the range investigated but is less marked
at large positive angles of attack for upper-surface
spoilers. The ineffectiveness of this spoiler in
increasing lift might be a distinct disadvantage during
high-speed maneuvering. The data of reference 6, how-
ever, indicate that rear spoilers used for lateral
control at high speed on wings show no objectionable
lag in effectiveness with projection. The present data
thus are not conclusive for high-speed flight.

The slope of the curves of lift-coefficient incre-
ment for the rear spoiler (fig. 13) is similar to that
for the plain flap (fig. 17). Except for the range in
which the spoiler is ineffective, a spoiler projection
of about 0.06c corresponds to a flap deflection of
about 10°.

A serious disadvantage of the rear spoiler alone
is its excessively large drag at large projections. It
is estimated that, if a high-speed fighter airplane
required an elevator deflection of 10° in a tight turn,
the drag of an equally effective spoiler would be about
18 times the drag of the elevator. This high drag would
produce a stabilizing moment unfavorable to depressing
the tail in the landing maneuver.

Forward spoiler alone.- With the spoiler at the
0.15c location, the values of the lift-coefficient
increment vary erratically with changes in spoiler
height and angle of attack (figs. 11 and 19). With
the spoiler on the upper surface and the model at a
positive angle of attack, the lift-coefficient incre-
ment increases negatively with an increase in spoiler
projection; with the spoiler on the upper surface and
the model at a negative angle of attack, the increment
increases positively. With the spoiler on either sur-
face and the model at a low angle of attack, the results
show an uncertain variation in the increments of lift
coefficient and flap hinge-moment coefficient. The
forward spoiler caused all the aerodynamic coefficients
to vary erratically throughout the lift range.

Forward spoiler and flap.- In an effort to study
the performance of the model with the forward spoiler
and the flap operating simultaneously, the data of
figure 12 were replotted in figures 20 and 21 with a
spoiler projecting 0.05c for every 10° of flap deflec-
tion. A comparison of figures 20 and 21 with figure 19
indicates that deflecting the flap in conjunction with
the spoiler increases the negative value of Δc_l at a
positive angle of attack; but, as with the forward
spoiler alone, the results are uncertain at zero and
negative angles of attack.

An improvement in performance seemed possible by
use of a delayed-action spoiler. Such a condition was
investigated with the spoiler remaining within the air-
foil contour until the flap was deflected -5° and then
projecting 0.05c for every 10° of flap deflection
(fig. 22). This arrangement proved only slightly better
than that in which the flap and spoiler operated
simultaneously, and the results are still uncertain at
zero and negative angles of attack.

The forward spoiler on the upper surface was tested
with the tab deflected ±15° and the flap neutral, and
the results are presented in figure 13. Although no
analysis of these data was made, it is obvious that
this combination has the same characteristics as the
forward spoiler and flap combination.

The forward spoiler alone or in combination with a
flap or tab appears to be unsatisfactory, because of the
difference in the effect of the spoiler at positive and

negative angles of attack. The flap hinge-moment coef-
ficients are also very erratic when the forward spoiler
is projected (figs. 11 to 13).

Combination of forward and rear spoilers on upper
surface.- From the data of figure 14, the curves of
figures 23 and 24 were plotted to show the effect of
two systems of operation of double spoilers on the
upper surface of the airfoil. With the two spoilers
operating simultaneously (fig. 23), the effect on lift
at an angle of attack of 8° at small spoiler projec-
tions is of the same magnitude as with the rear spoiler
alone (fig. 18). At angles of attack of 0° and -8°, the
two spoilers tend to cancel the effect produced by
either one acting alone. With the delayed-action
system (fig. 24), the results at all angles of attack
are too erratic for this system to be used as a control
device. The section data for the double-spoiler arrange-
ments show the same erratic characteristics (fig. 14)
as noted for the forward spoiler alone.

Combinations of spoilers on upper and lower
surfaces.- Data for various combinations of rear
spoiler on the lower surface and forward spoiler on the
upper surface are given in figure 15. At any particular
constant value of forward-spoiler height and angle of
attack, projecting the rear spoiler increases the lift
positively. In order to apply the data of figure 15
directly to the landing problem, it therefore is necessary
to think of the combination as a forward spoiler on the
lower surface and a rear spoiler on the upper surface
with the signs of the angle of attack and the lift coef-
ficient reversed. This assumption is valid because the
airfoil is symmetrical and the flap and tab were not
deflected.

Data are presented for a rear spoiler on the upper
surface and a forward spoiler on the lower surface in
figure 16. These data are a replot of some of the
curves of figure 15 with the signs reversed to give a
negative increment of lift coefficient with an increase
in spoiler height and with a constant proportional
variation in the heights of the forward and rear spoilers.

Increments of airfoil section lift coefficient as a function
of spoiler projection are presented in figures 25 and 26 for

combinations of forward and rear spoiler. The combina-
tion spoilers have very high effectiveness for positive
angles of attack and appear to be satisfactory for
depressing the tail of an airplane in the landing
maneuver. The combination with a delayed-action
forward spoiler (fig. 26) is more effective than the
combination with spoilers acting simultaneously at an
angle of attack of 0° but is less effective at an angle
of attack of 8°. Even these combinations, which were
very effective for the landing maneuver, could hardly
be used alone as a pitch or yaw control device because
of their erratic and adverse effects throughout the
angle-of-attack range.

<center>Complete Model A</center>

Effect of elevator deflection.- The effect of
elevator deflection on the aerodynamic characteristics
of model A near the ground board is shown in figure 27.
With the flaps either neutral or deflected, an elevator
deflection of -30° is required to trim the model at
maximum lift. As may be expected, the hinge-moment
coefficients are high at the elevator deflection for
trim. The stick forces, based on these hinge-moment
coefficients, for an actual airplane in the landing
maneuver would be high but not excessive.

Effect of spoiler projection.- The effect of
spoiler projection on the aerodynamic characteristics
of model A is shown in figure 28. In these tests the
spoiler projections were equal to the spoiler chords.
The data show that a spoiler chord of at least $0.15c_{t_{av}}$
is required to trim the model near maximum lift with
the flaps either neutral or deflected.

Effect of spoiler gap.- The effect of spoiler gap
on the aerodynamic characteristics of model A with a
spoiler of constant chord (spoiler on upper surface) is
shown in figure 29. The maximum effectiveness is obtained
when the spoiler projection is equal to the spoiler
chord. The effectiveness decreases when the projection
is greater than the chord; that is , when there is a gap
between the surface of the tail and the lower edge of
the spoiler. This loss in effectiveness increases with
an increase in gap between the spoiler and tail.

Effect of spoiler combinations.- In an effort to
increase the effectiveness of the spoilers, two com-
binations of spoilers having different chords were tested
on model A and the results are shown in figure 30. With
both spoilers on the upper surface, the effectiveness is
less than the effectiveness of a $0.06c_{t_{av}}$ rear spoiler
alone (fig. 28). This result is in agreement with the
results of the section data previously discussed, which
indicate that two spoilers on the same surface tend to
cancel the effects of each other. With the forward
spoiler on the lower surface and the rear spoiler on
the upper surface, however, a quite effective combina-
tion is obtained and it is necessary to project the
rear spoiler only $-0.09c_{t_{av}}$ and the forward spoiler
only $-0.06c_{t_{av}}$ (fig. 30) to obtain the same effec-
tiveness as for the $-0.15c_{t_{av}}$ rear spoiler alone
(fig. 23). If spoilers were used in landing an air-
plane, the use of double spoilers rather than a rear
spoiler alone would be advantageous, since a $0.15c_{t_{av}}$
rear spoiler might prove difficult to retract within
a tail surface contour of normal thickness.

Comparison of elevators and spoilers.- The elevator
deflections and the spoiler projections required to trim
model A at any given lift coefficient are shown in fig-
ure 31. A 3-percent spoiler projection generally is
equally as effective as an elevator deflection of $4°$.
Since the spoilers on this model spanned 78 percent of
the tail span, this relative effectiveness is in very
close agreement with the relative effectiveness of the
spoiler-flap arrangement of the model in two-dimensional
flow.

Complete Model B

The effects on the aerodynamic characteristics of
various elevator deflections and spoiler projections
with the horizontal tail of model B in both its normal
and raised locations are shown in figures 32 to 34.
In order to analyze the pertinent information provided
by these data, the elevator deflection required to trim
is plotted against the model angle of attack (fig. 35).
The results (fig. 35) are presented for a forward center-
of-gravity location of $0.14c'$ for a stabilizer setting
of $-1.4°$. The center-of-gravity location used in this
analysis is the most forward, since it would be the

critical location in landing. A stabilizer setting of -1.4°
is used since it has been estimated that this setting
would be required for the elevator to have a desirably
small positive deflection for a normal center-of-gravity
location at high speed.

The elevator of model B was not sufficient to trim
the model near the ground and thus spoilers were used to
provide auxiliary negative lift near the ground.

Effect of tail location.- With the tail in the
normal location (fig. 35), a 0.10c_t spoiler and an
elevator deflection of 25° are required to attain the
landing attitude. The curves of figure 35 show that,
if a spoiler is linked so that it projects in propor-
tion to the elevator deflection, the resulting com-
bination gives satisfactory trim characteristics.
With the 0.10c_t spoiler, the elevator deflection
required to land is less with the raised tail than
with the tail in the normal location. The reason
for the larger elevator deflection required for the
raised tail without spoilers seems to be an unexplained
decrease in elevator effectiveness. The data also indi-
cate that spoiler effectiveness decreases considerably
as the elevator deflection is increased.

Effect of spoilers on stick force.- From the data of
figures 32 to 34, the stick force required to trim
model B near the ground has been estimated for a full-
scale airplane and the results are presented in fig-
ure 36. The addition of a spoiler causes an unfavorable
variation of stick force with angle of attack. The
elevator overbalance, at large spoiler projections and
elevator deflections, occurs because the spoiler in
front of the elevator deflects the air so that the
load on the portion of the elevator behind the hinge
line is decreased. The elevator balance, which has
been little affected by the spoiler, contributes its
full influence and overbalance thus results. Spoilers
used in conjunction with the elevator or rudder would
not be desirable because of the erratic and overbalancing
effect produced on the hinge moments of the conventional
control surface.

Effect of spoiler combinations.- Model B was tested
with various spoiler combinations in an attempt to
determine their relative merits. The results of the
tests (fig. 37) are quite erratic, probably because of

the nonuniform variation in downwash angle and dynamic
pressure at the tail throughout the angle-of-attack
range for model B. The average downwash angle through-
out the model angle-of-attack range is about 6.5°. The
large change in the slope of the pitching-moment curves
thus occurs in the region of low angle of attack at the
tail. The forward spoilers, as well as combination
spoilers, generally cause a large unfavorable change
in trim in the region in which the model angle of attack
is low and the tail angle of attack is negative. The
erratic and often adverse effect of forward spoilers at
low and negative angles of attack is also evident in the
section data previously discussed.

The combinations of forward spoilers on the lower
surface and rear spoilers on the upper surface are
effective at positive tail angles of attack but have
the same disadvantages as all forward spoilers in that
their effect is adverse at low and negative tail angles
of attack. Spoilers on model B as well as model A
showed little possibility of replacing conventional
tail control surfaces on airplanes but might be used as
auxiliary control devices if a number of the serious
disadvantages that they present can be remedied or
tolerated.

The reason the pitching-moment curve of model A
(fig. 37) did not show an irregularity as did the
pitching-moment curve of model B with combination
spoilers is unknown, but the difference might be
caused by the existence of a more regular flow field
near the tail of model A.

Effect of elevator gap behind spoiler.- The data
of figures 33 and 35 obtained in three-dimensional flow
indicate that the effectiveness for a small spoiler projec-
tion is larger than section data indicate. This change
in effectiveness for small spoiler projections was
thought to be some function of the elevator gap. A
few tests of a typical fighter model were therefore
made to determine the effect of elevator gap on
spoiler effectiveness. These tests were made with the
model not in the presence of a ground board, but this
condition should have little effect on the relative
merits of the various arrangements tested. A $0.008c_t$
spoiler was used and the results show that a gap behind
this small spoiler causes the spoiler to become very
effective (fig. 38). The small spoiler causes a large

negative peak pressure near the gap, which induces a
large air flow through the gap. The flow through the
gap results in an upwash much the same as that obtained
by deflecting an elevator upward. This increase in
spoiler effectiveness by the use of an elevator gap has
previously been reported (reference 7). If spoilers
were used on airplane tail surfaces, it therefore would
be a definite advantage to locate them just ahead of an
unsealed gap or slot through the tail surface.

CONCLUSIONS

Spoilers have been tested at low speed on a model
in two-dimensional flow and on the tail surfaces of
three complete airplane models. The following con-
clusions were drawn from an analysis of the results of
these tests:

1. Spoilers showed little possibility of replacing
conventional tail control surfaces on airplanes but
might be used as auxiliary control devices if a number
of the serious disadvantages that they present can be
remedied or tolerated. These disadvantages and problems,
however, were quite serious and the widespread use of
spoilers on tail surfaces does not appear likely.

2. Spoilers generally should be located at the
rear portion of the tail surface. It might be advan-
tageous, however, to locate an auxiliary spoiler forward
on the lower surface of the horizontal tail in order to
aid in depressing the tail in the landing maneuver. In
flight, the use of this auxiliary spoiler, when spoilers
alone are used for landing, might be necessary if the
spoiler projection on the upper surface were limited to
the airfoil thickness.

3. A forward spoiler alone or in conjunction with
the conventional control surface gave unsatisfactory
results because of its erratic action throughout the
angle-of-attack range.

4. A forward auxiliary spoiler should be located
on the opposite side of the tail surface from the rear
spoiler, since two spoilers on the same side of the tail
surface tended to cancel the effects obtained by the
use of either spoiler alone.

5. A gap between the spoiler and tail surface resulted in a loss in spoiler effectiveness that increased with an increase in gap.

6. In flight the drag produced by a spoiler used to replace a conventional control surface would be many times as great as that of a conventional control surface. A tail drag of large magnitude would be a decided disadvantage.

7. The ineffectiveness for small spoiler projections might be eliminated by locating the spoiler just ahead of an unsealed gap or slot through the tail surface.

8. Spoilers used in conjunction with the elevator or rudder would not be desirable because of the erratic and overbalancing effect produced on the hinge moments of the conventional control surface.

Langley Memorial Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Field, Va.

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2. Wenzinger, Carl J., and Harris, Thomas A.: The
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3. Sears, Richard I., and Hoggard, H. Page, Jr.: Wind-
   Tunnel Investigation of Control-Surface Charac-
   teristics. II - A Large Aerodynamic Balance of
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   on an NACA 0009 Airfoil. NACA ARR, Aug. 1941.

4. Recant, Isidore G.: Wind-Tunnel Investigation of
   Ground Effect on Wings with Flaps. NACA TN No. 705,
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   Control-Surface Characteristics. I - Effect of
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   Flap. NACA ARR, June 1941.

6. Laitone, Edmund V.: An Investigation of the High-
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7. Wenzinger, Carl J., and Rogallo, Francis M.: Wind-
   Tunnel Investigation of Spoiler, Deflector, and
   Slot Lateral-Control Devices on Wings with Full-
   Span Split and Slotted Flaps. NACA Rep. No. 706,
   1941.

TABLE I.- RÉSUMÉ OF TESTS IN TWO-DIMENSIONAL FLOW

Test	Forward-spoiler height (fraction c)	Rear spoiler Height (fraction c)	Rear spoiler Surface	Flap deflection (deg)	Tab deflection (deg)	Figure
1	None	0.01	Upper	0	0	16
2	0.01	.025	Upper	↓	↓	14(a), 16
3		.025	Lower			15(a)
4		.05	Upper			14(a)
5		.05	Lower			15(a)
6		.10	Upper			14(a)
7		.10	Lower			15(a)
8		.15	Upper			14(a)
9		.15	Lower			15(a)
10		None	-----	↓		11, 12(a)
11			-----	10		12(a)
12			-----	-10		12(a)
13			-----	20	↓	12(a)
14			-----	-20		12(a)
15		↓	-----	0	15	13(a)
16	↓		-----		-15	13(b)
17	.03	0.05	Upper	↓	0	14(b), 16
18		.05	Lower			15(b)
19		.10	Upper			14(b)
20		.10	Lower			15(b)
21		.15	Upper			14(b)
22		.15	Lower	↓		15(b)
23		None	-----			11, 12(b), 14(b), 15(b)
24			-----	10		12(b)
25			-----	-10		12(b)
26			-----	20	↓	12(b)
27			-----	-20		12(b)
28			-----	0	15	13(a)
29	↓	↓	-----	0	-15	13(b)

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TABLE I.- RÉSUMÉ OF TESTS IN TWO-DIMENSIONAL FLOW - Concluded

Test	Forward-spoiler height (fraction c)	Rear spoiler		Flap deflection (deg)	Tab deflection (deg)	Figure
		Height (fraction c)	Surface			
30	0.06	0.10	Upper	0	0	14(c), 16
31		.10	Lower			15(c)
32		.15	Upper			14(c)
33		.15	Lower			15(c)
34		None	-----			11, 12(c), 14(c), 15(c)
35			-----	10		12(c)
36			-----	-10		12(c)
37			-----	20		12(c)
38			-----	-20		12(c)
39			-----	0	15	13(a)
40			-----		-15	13(b)
41	.09	0.10	Upper		0	14(d)
42		.10	Lower			15(d)
43		.15	Upper			14(d), 16
44		.15	Lower			15(d)
45		None	-----			11, 12(d), 14(d), 15(d)
46			-----	10		12(d)
47			-----	-10		12(d)
48			-----	20		12(d)
49			-----	-20		12(d)
50			-----	0	15	13(a)
51			-----		-15	13(b)
52	None		-----		15	13(a)
53			-----		-15	13(b)
54			-----		0	9, 10, 11, 16
55			-----	-10		9
56			-----	-20		9
57			-----	10		9
58			-----	20		9
59		0.025	Upper	0		10
60		.05	Upper			10
61		.10	Upper			10
62		.15	Upper			10

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TABLE II.- RÉSUMÉ OF TESTS OF MODEL A

[Three-dimensional flow; complete model; landing gear down; $\delta_r = 0°$]

Test	δ_f (deg)	i_t (deg)	δ_e (deg)	c_s (fraction of t_{av})	δ_s (fraction of t_{av})	Figure
1	0	2.25	0	None	None	27(a)
2			-10			27(a)
3			-15			27(a)
4			-30			27(a)
5			-45			27(a)
6			0	0.06	-0.06	28(a)
7				.09	-.09	28(a)
8				.15	-.15	28(a)
9				.25	-.25	28(a)
10	45	2.00		None	None	27(b), 28(b), 29
11			-10			27(b)
12			-15			27(b)
13			-30			27(b)
14			0	0.06	-0.06	28(b)
15				.09	-.09	28(b), 29
16				.15	-.15	28(b)
17				.25	-.25	28(b)
18				.09	-.15	29
19				.09	-.21	29
20				{a.09, b.06}	{a-.09, b-.06}	30
21				{a.09, b.06}	{a-.09, b.06}	30

[a]Rear spoiler in combination.
[b]Forward spoiler in combination.

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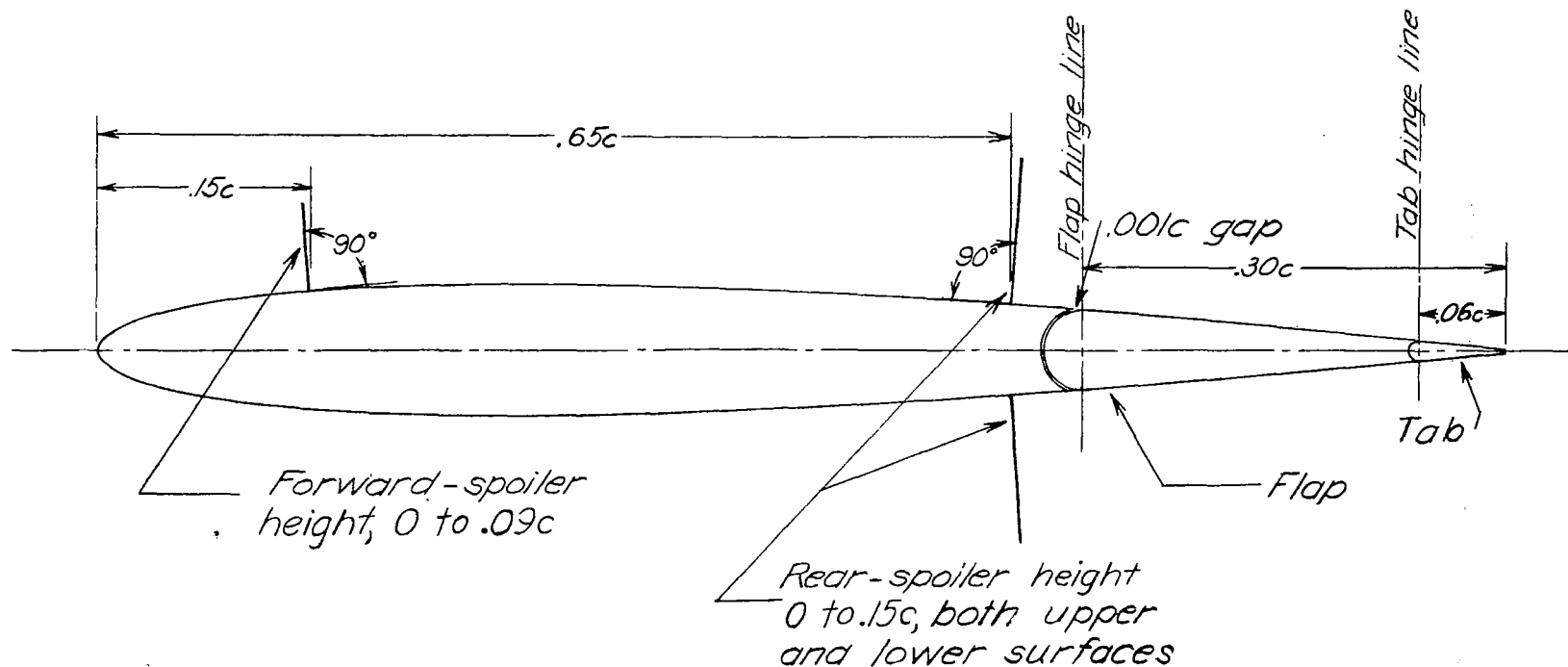
Figure 1.-NACA 0009 airfoil section showing size and location of flap, tab, and spoilers. Airfoil chord=2 feet.

Fig. 1

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Fig. 2

30.72"

₵ elevator hinge

Surface	Area, sq. in.
Wing	1360
Horizontal tail	2.31
Vertical tail	119

Split flaps

5.6"

18.2"

4.22"

43"

c.g. 3.3°

89.5"

D = 24"

10°

Thrust line

4.8"

5.3° 2.25°

Model ₵

1.04"

c.g.
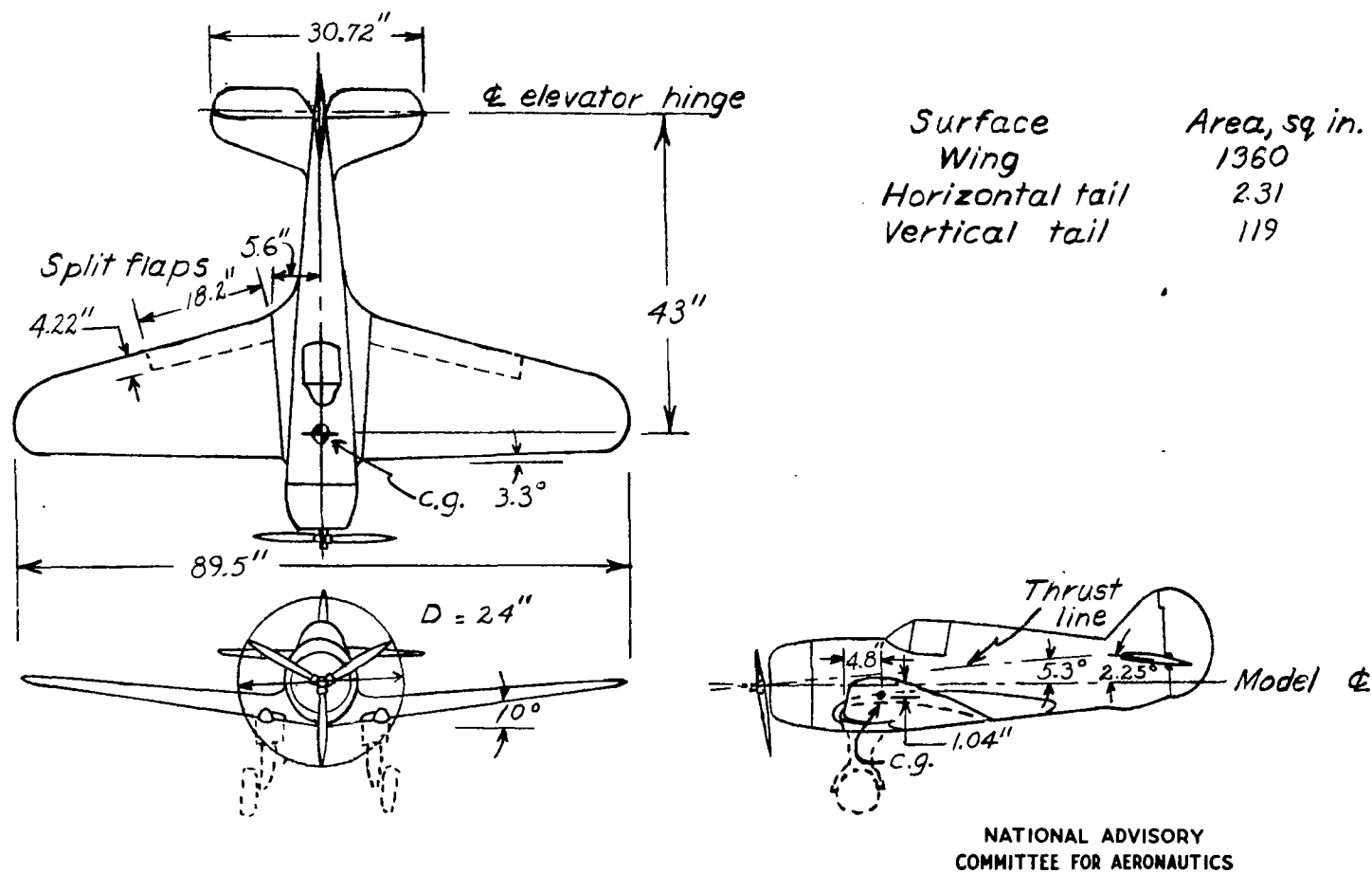
Figure 2.— Three-view drawing of model A.

15.36"

8.55"

6.3"

12"

1.68"

¢ elevator hinge

2.66"

.677 c_{tav}
c_{tav} = 8.25"
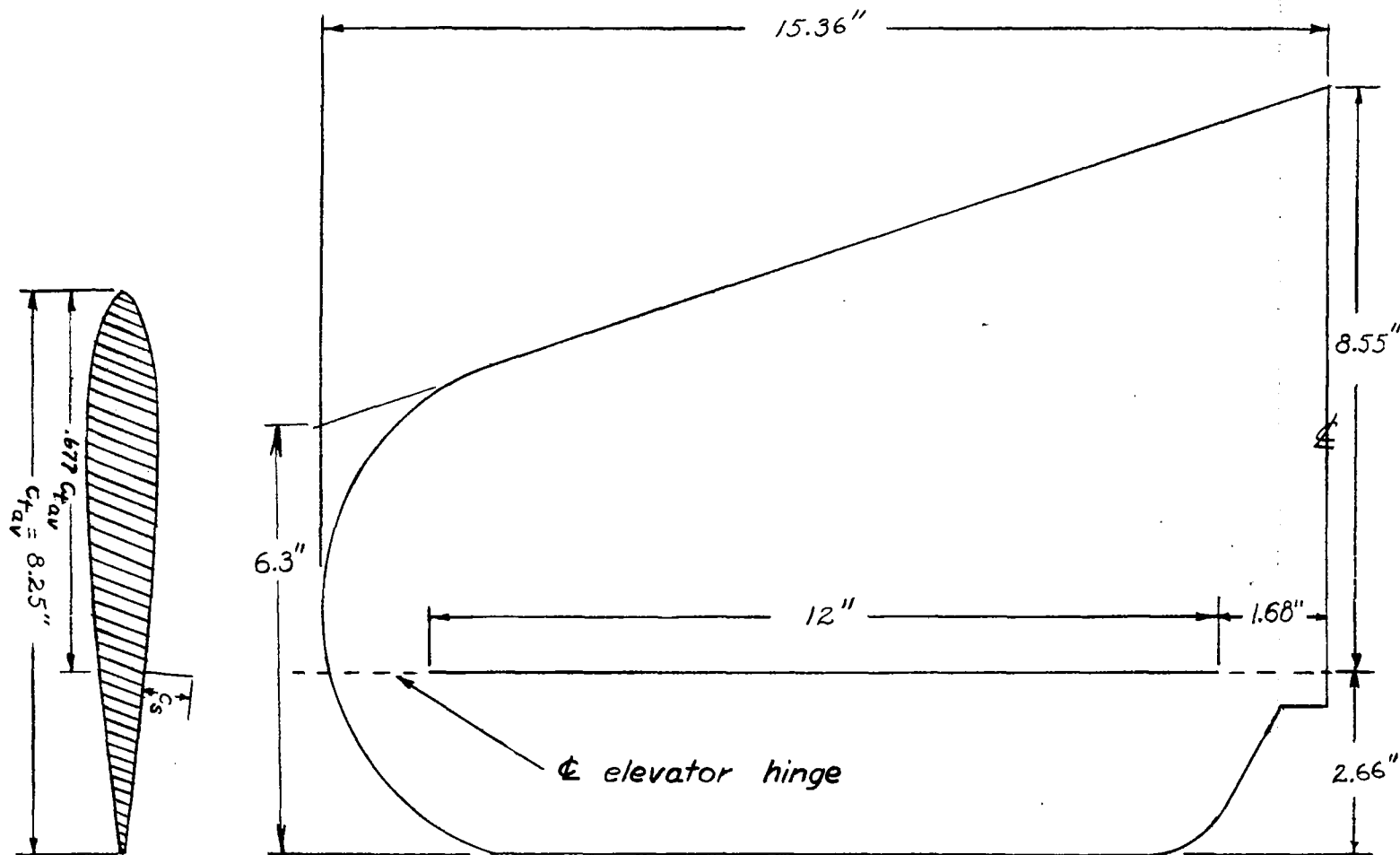
c_s

(a) Single spoiler.

Figure 3.- Location of spoilers on horizontal tail of model A.
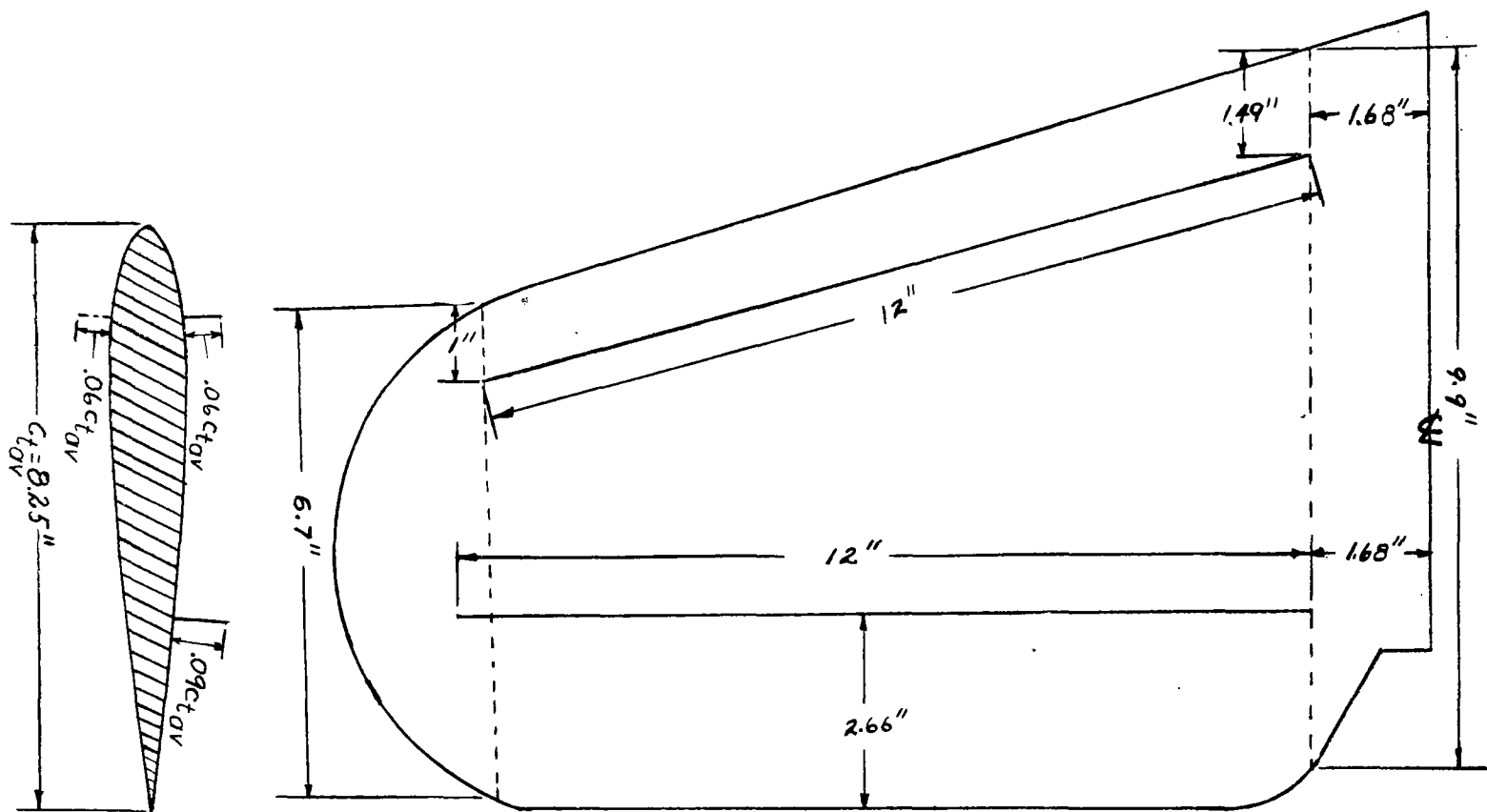
(b) Combination spoilers.

Figure 3.- Concluded.

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D = 21.76"

8°

33.50"

9"

34.65"

75.00"

Inboard flap

Outboard flap

8.08"

24.38"

Surface	Area, sq in.
Wing	958
Horizontal tail	179
Vertical tail	87

Slat

c.g. 18.1 percent c'

5.67"

16.41"

16.15"

.38"

c.g.
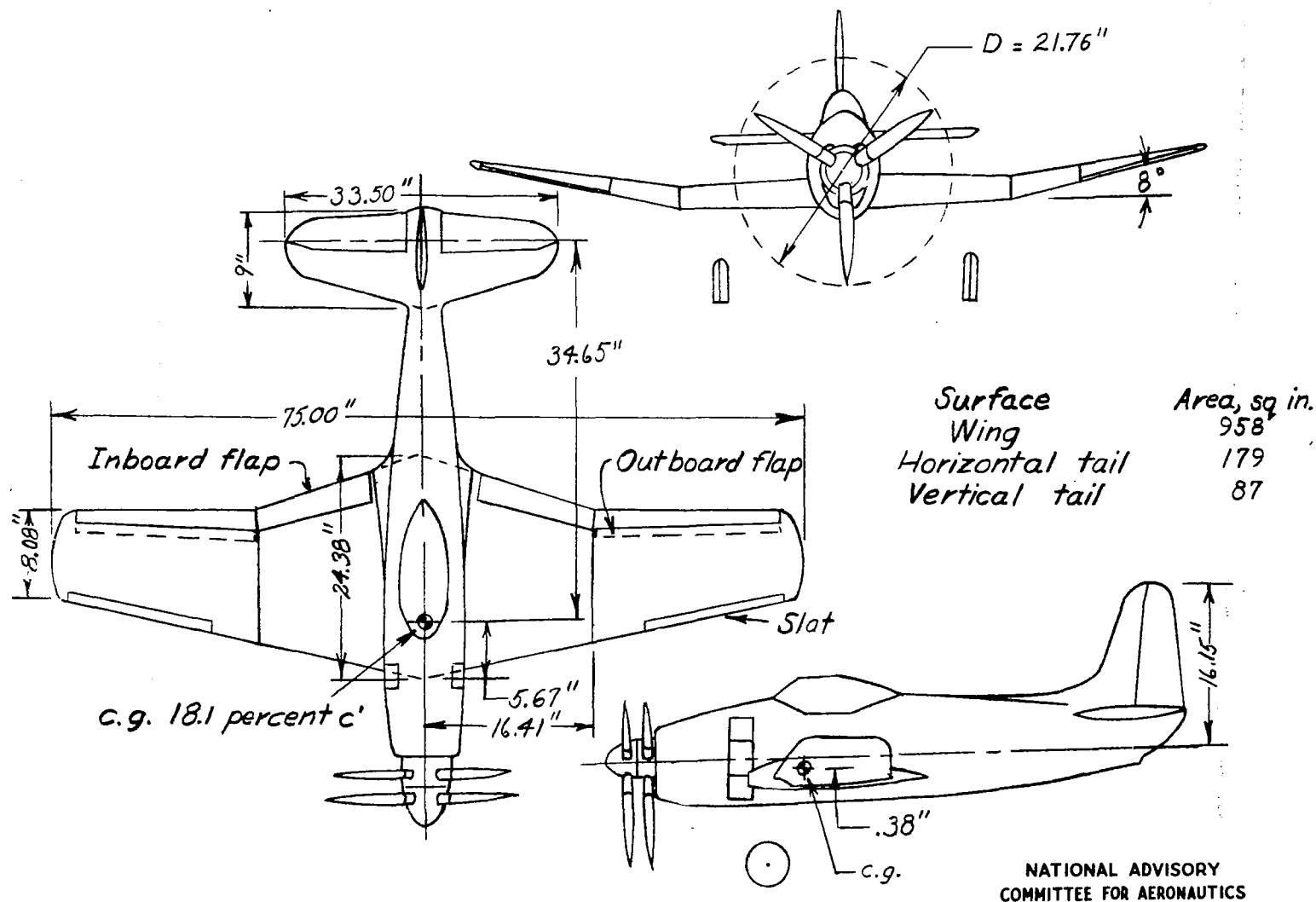
Figure 4.- Three-view drawing of model B.

Fig. 4

Fig. 5

.38" c.g. (.18 c')

5.67"

₵ fuselage

Theoretical
root section

13.61"

3.39" 1.70"

9.84"

Point about which model pivots in
changing angle of attack
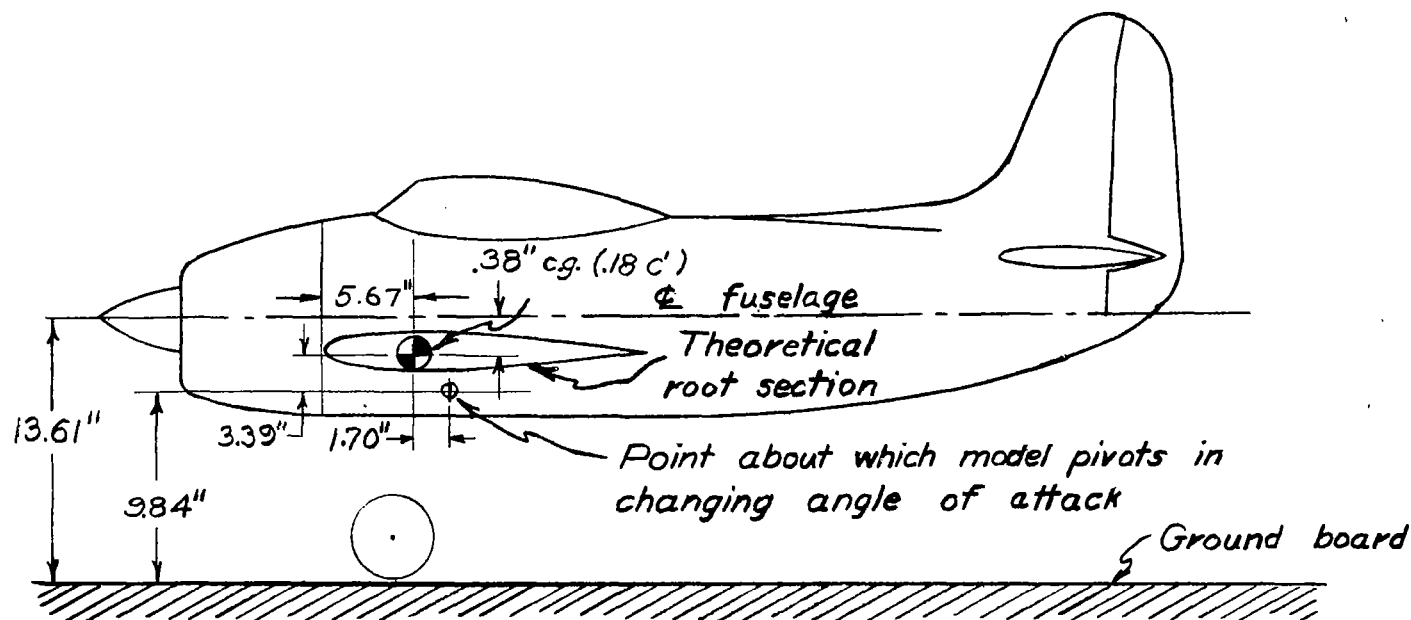
Ground board

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Figure 5.— Location of model B near ground board.

Spoiler height, c_s			
$0.01c_t$	$0.025c_t$	$0.050c_t$	$0.100c_t$

.06" gap

c_s

Hinge line

A

A

c_t

Typical section

33.50"

14.88"

A

6.3"

5.20"

2.69"

4"

9"

5.84"

Hinge line

Spoiler

Spoiler

A

1.45"
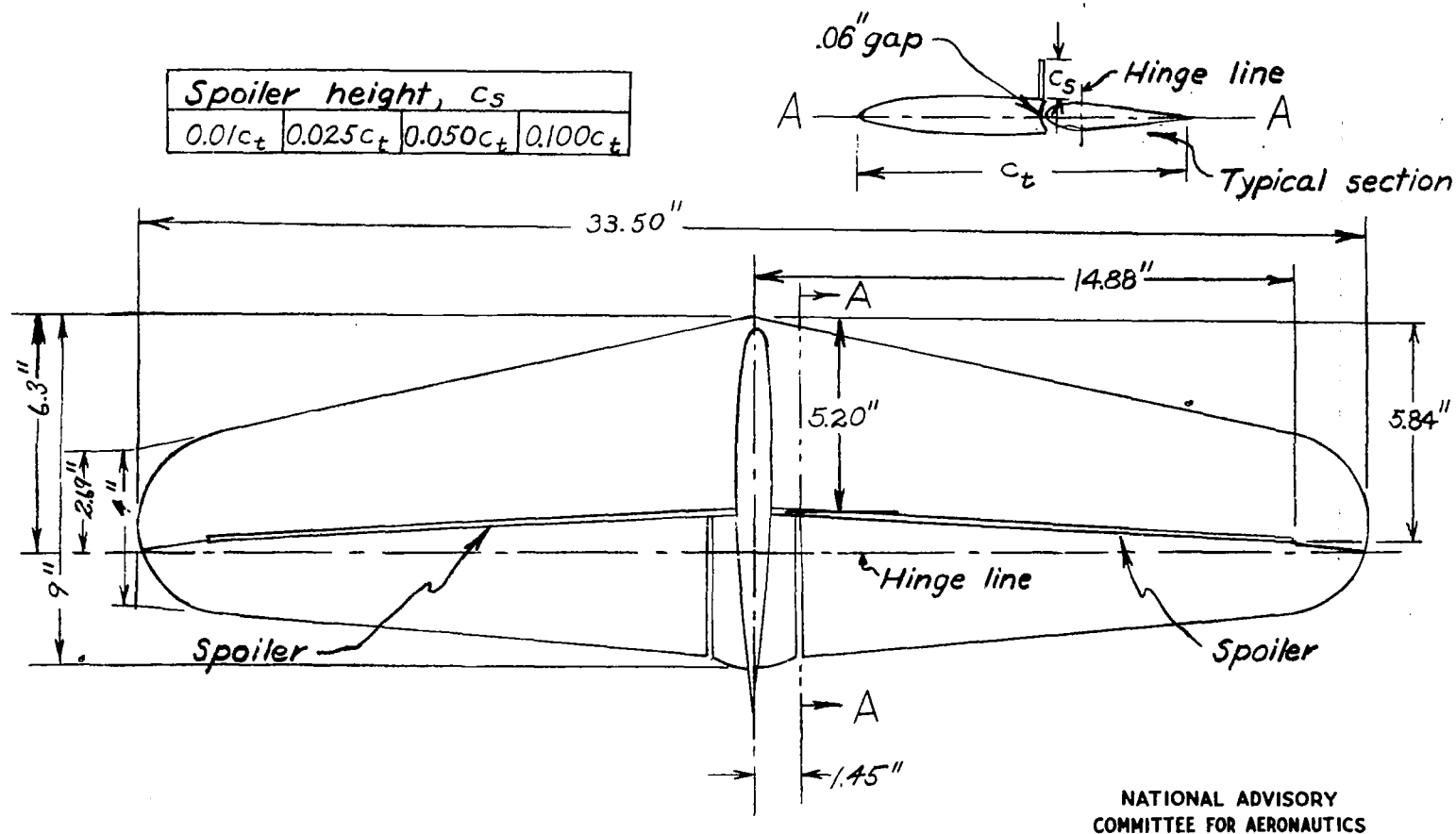
(a) Dimensions of spoiler and model.

Figure 6.- Horizontal tail of model B.

Raised location

Streamline strut

Normal location

4.0"

3.0"

¢ fuselage
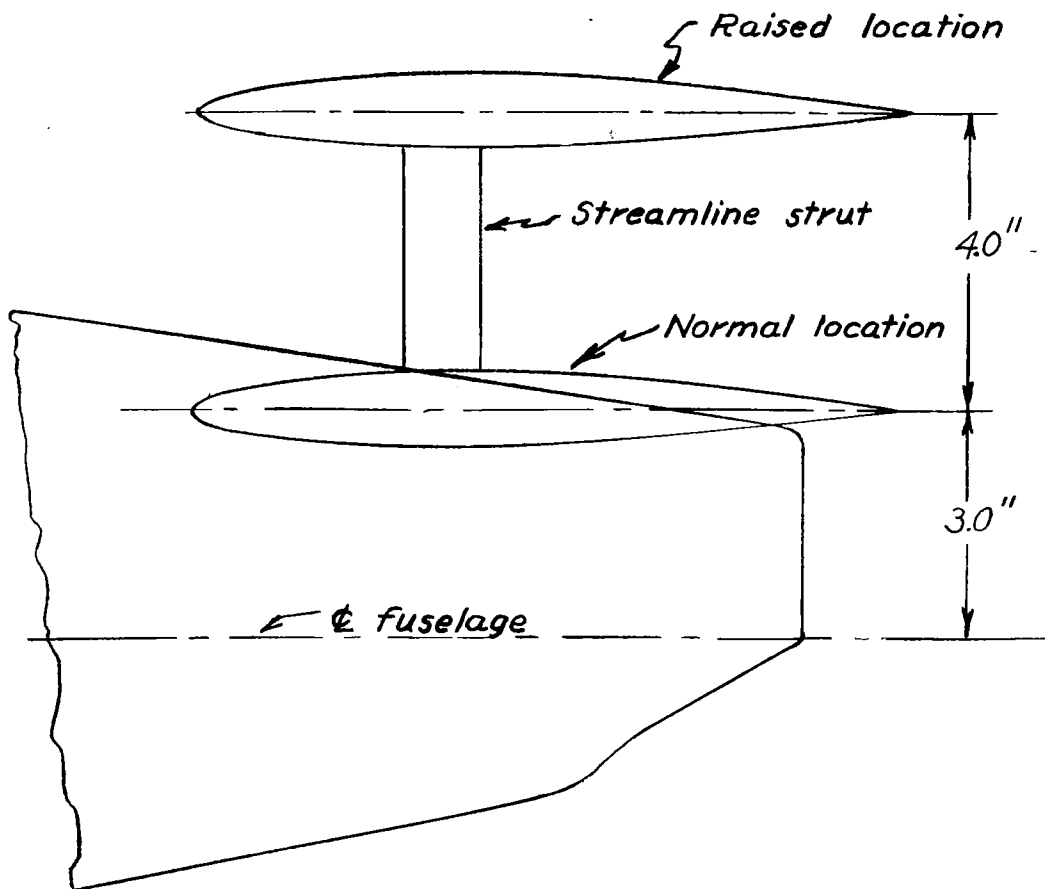
(b) Location of normal and raised
    tail.

Figure 6.- Concluded.
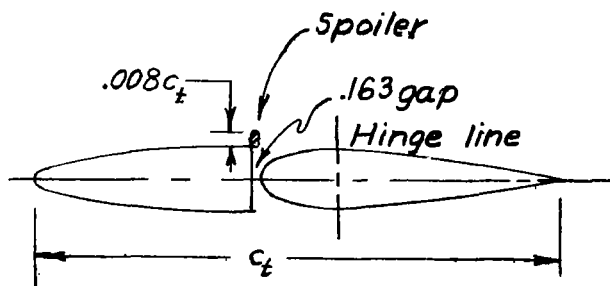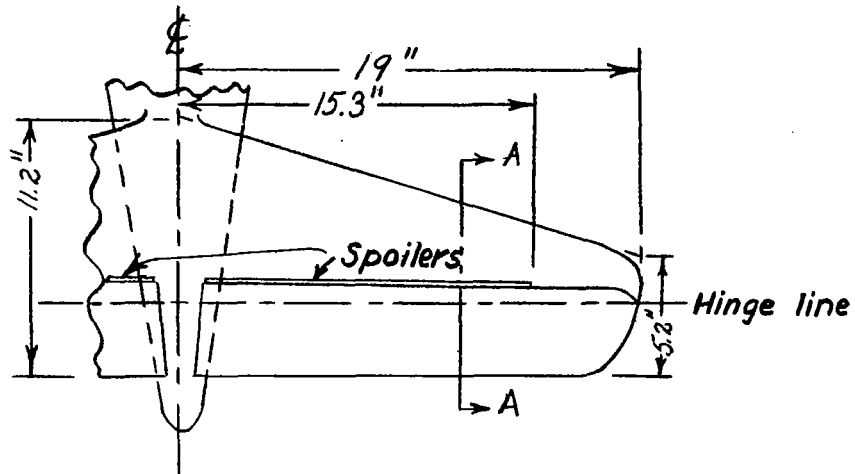
Section A-A

Figure 7.— Location of spoilers on horizontal tail of a typical fighter-airplane model.

Fig. 8   NACA ARR No. L5F28
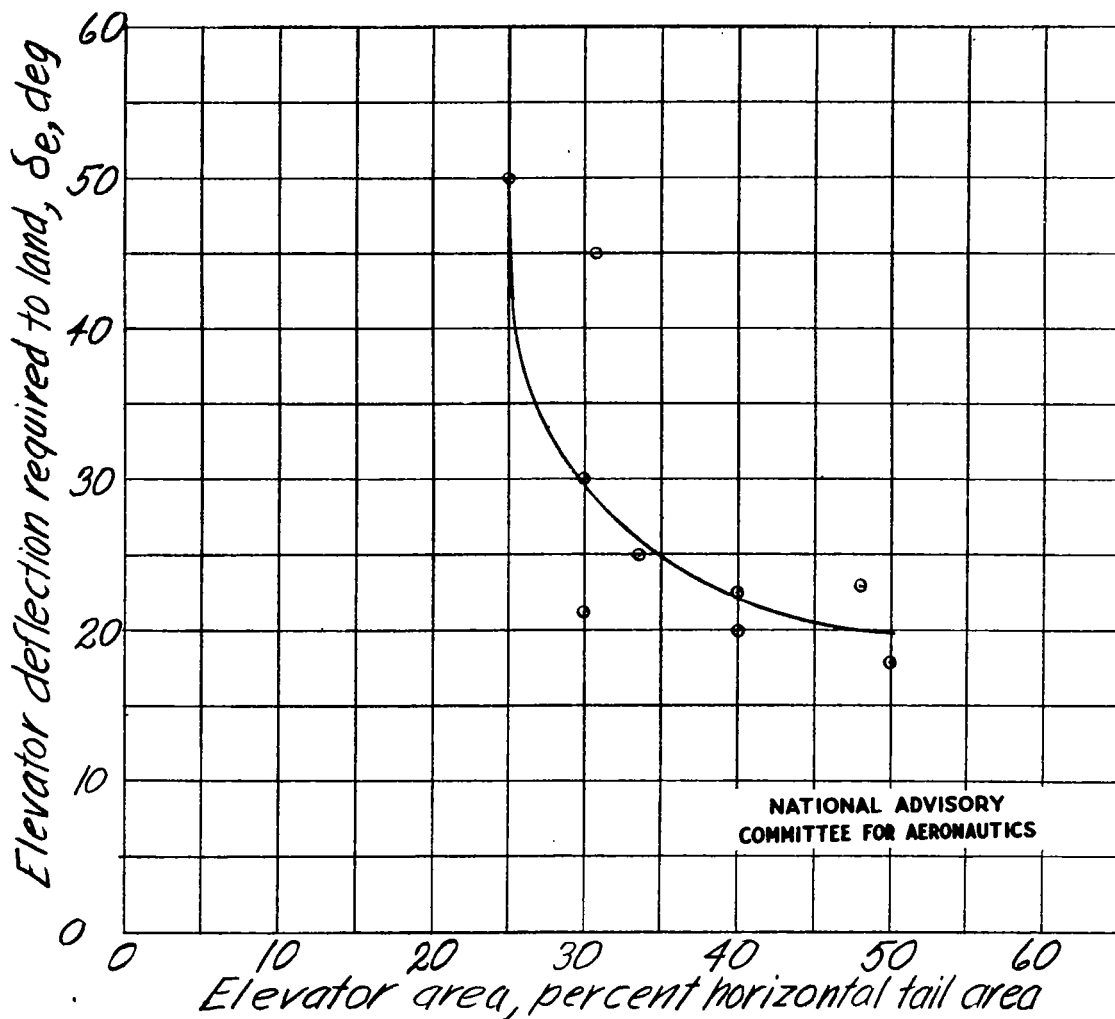
Figure 8.—Elevator deflection required to land as a function of elevator area for various fighter-airplane models. Models tested near ground board in Langley 7- by 10-foot tunnel.
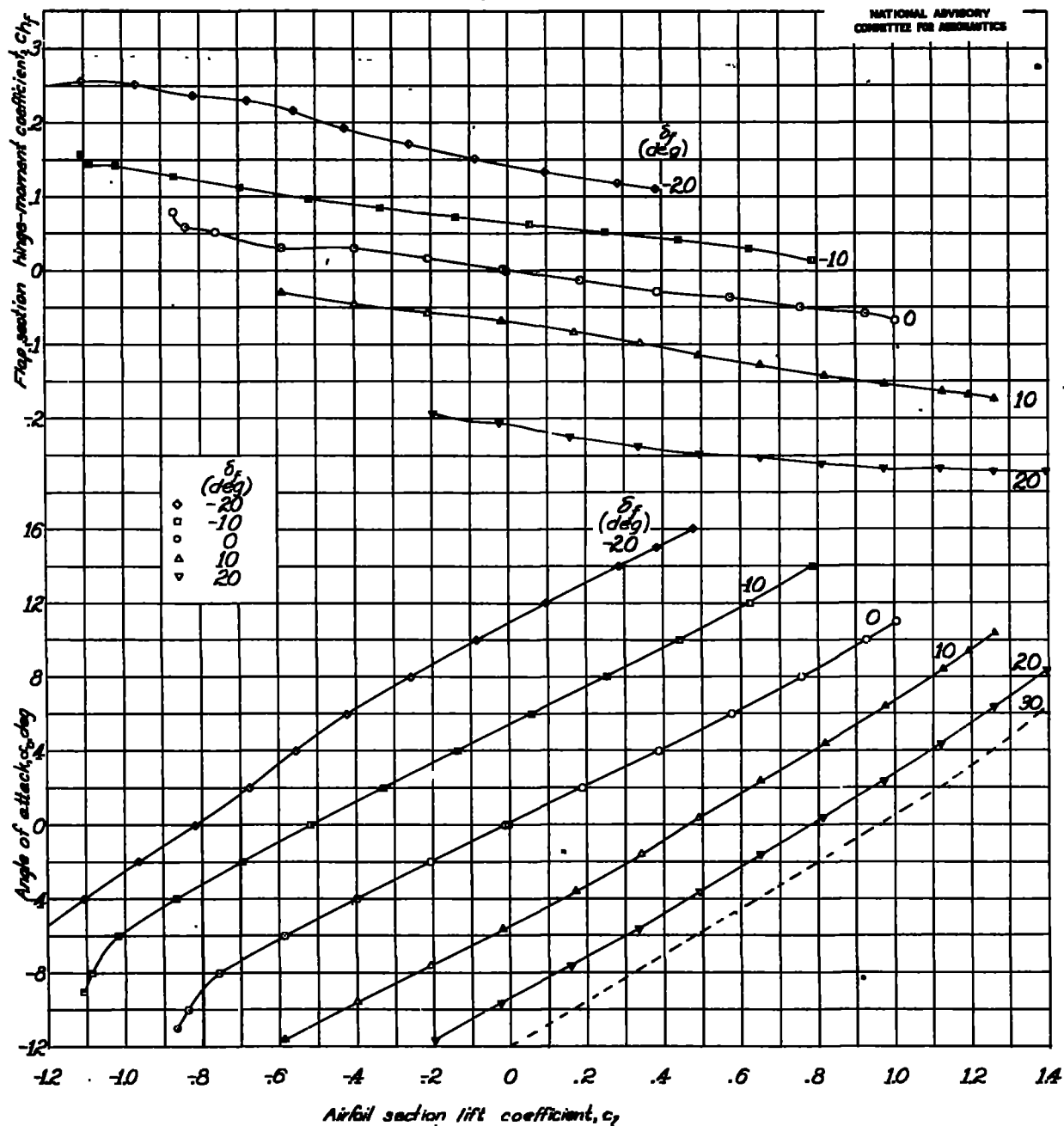
Figure 9.- Effect of flap deflection on the aerodynamic section characteristics of the plain airfoil. δ_t ·0°. (The curve for the flap deflection of 30° was obtained from reference 5.)

Fig. 9 Conc.   NACA ARR No. L5F28

Figure 9.- Concluded.
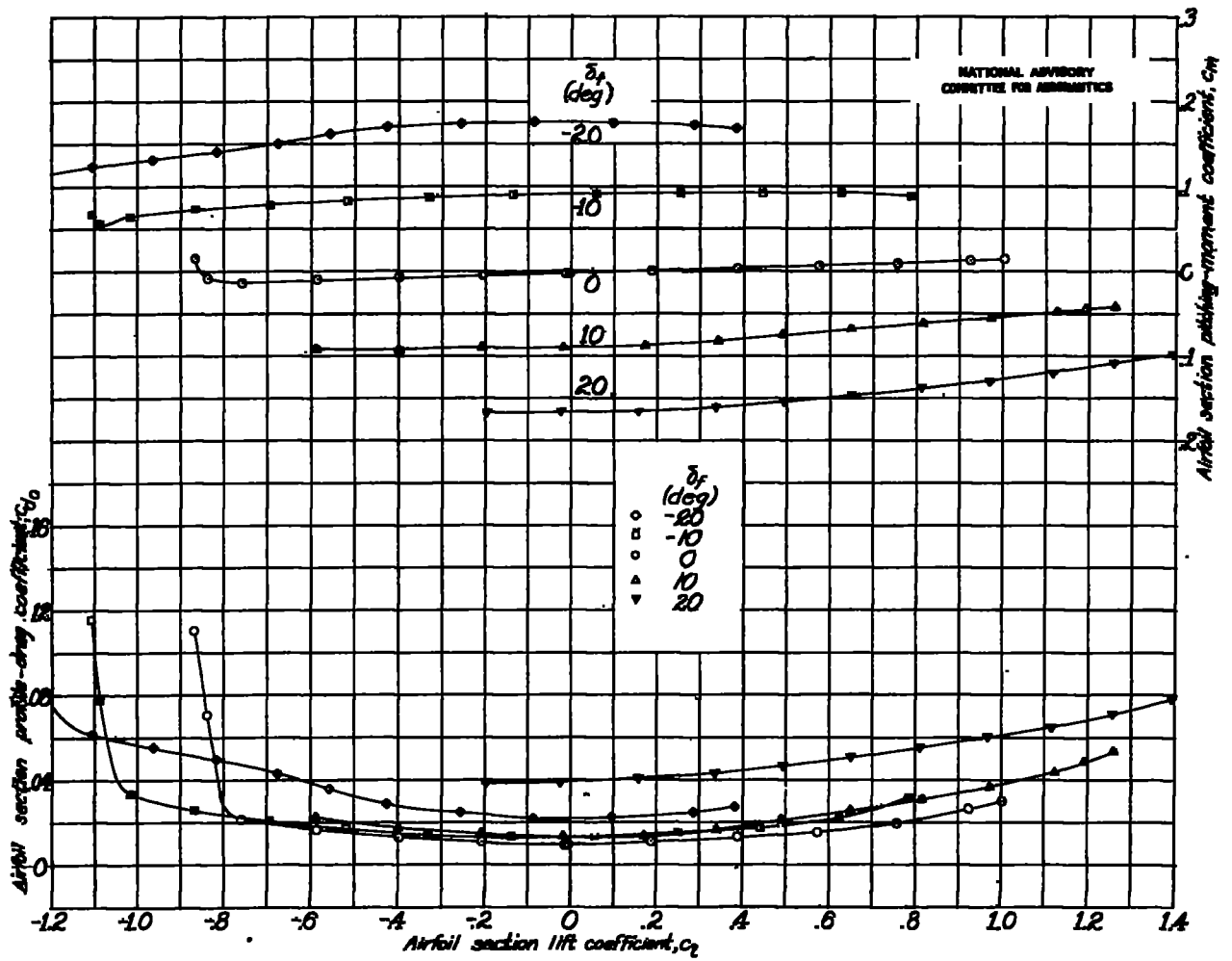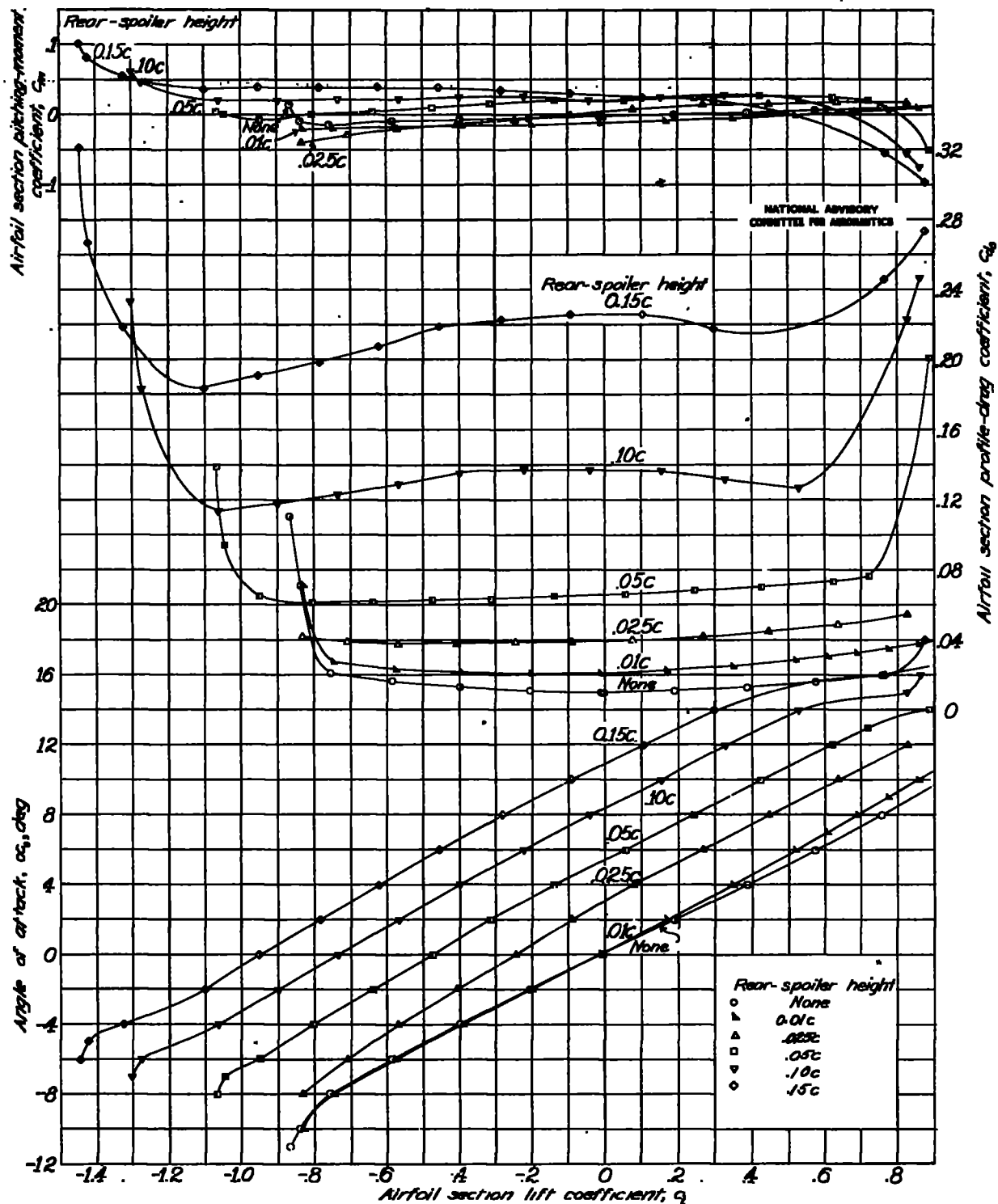
Figure 10.- Effect of rear-spoiler height on the aerodynamic section characteristics with spoiler at 0.65c on the upper surface of the airfoil. $\delta_f = \delta_t = 0°$.

Fig. 11   NACA ARR No. L5F28
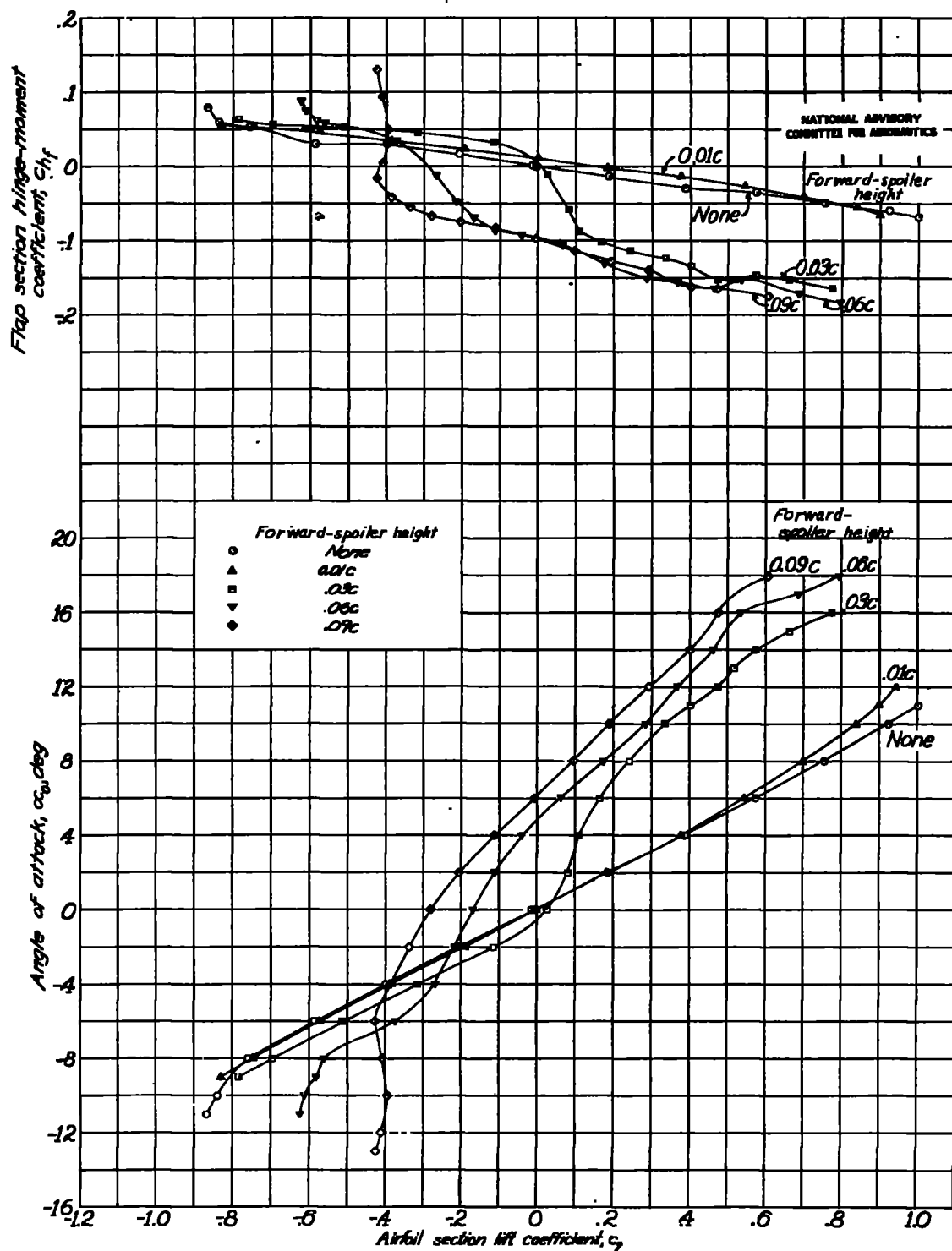
Figure 11.- Effect of forward-spoiler height, with constant flap deflection of 0°, on the aerodynamic section characteristics. Spoiler on upper surface at 0.15c. $\delta_f = 0°$.
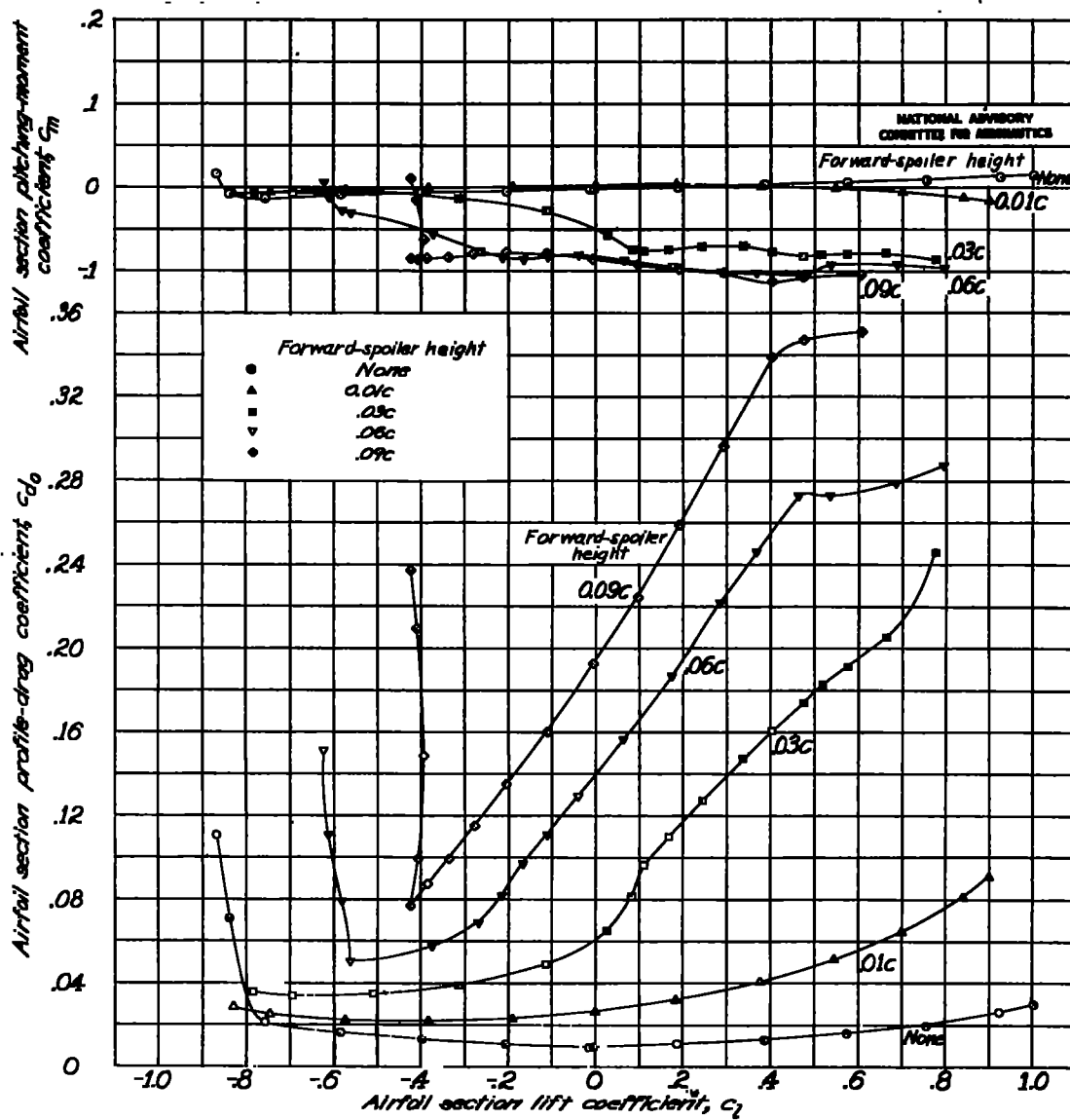
Figure 11.- Concluded.
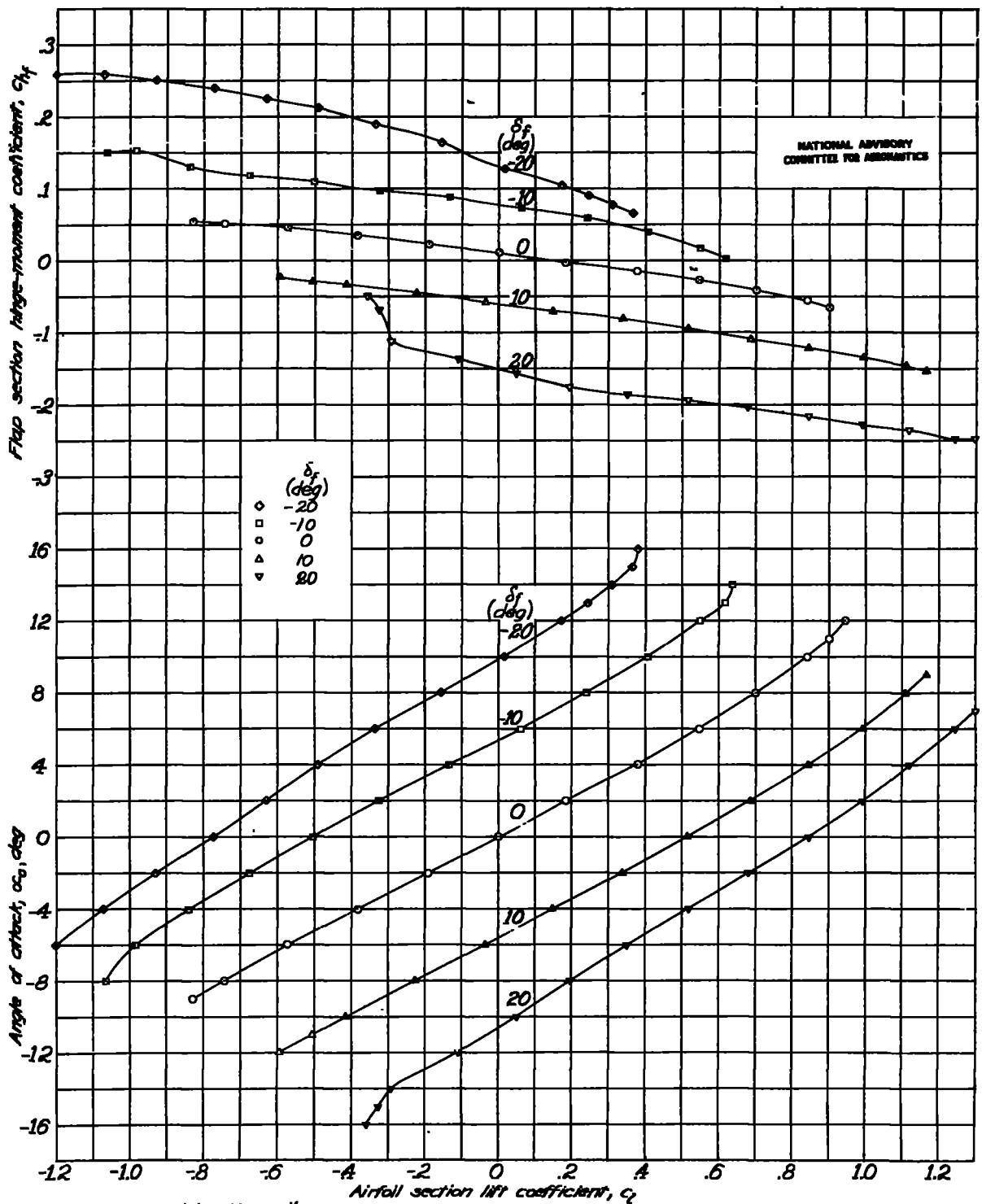
(a) 0.04c spoiler.
Figure 12.—Effect of flap deflection on the aerodynamic section characteristics with a spoiler at 0.15c on the upper surface of the airfoil. δ_t = 0°.
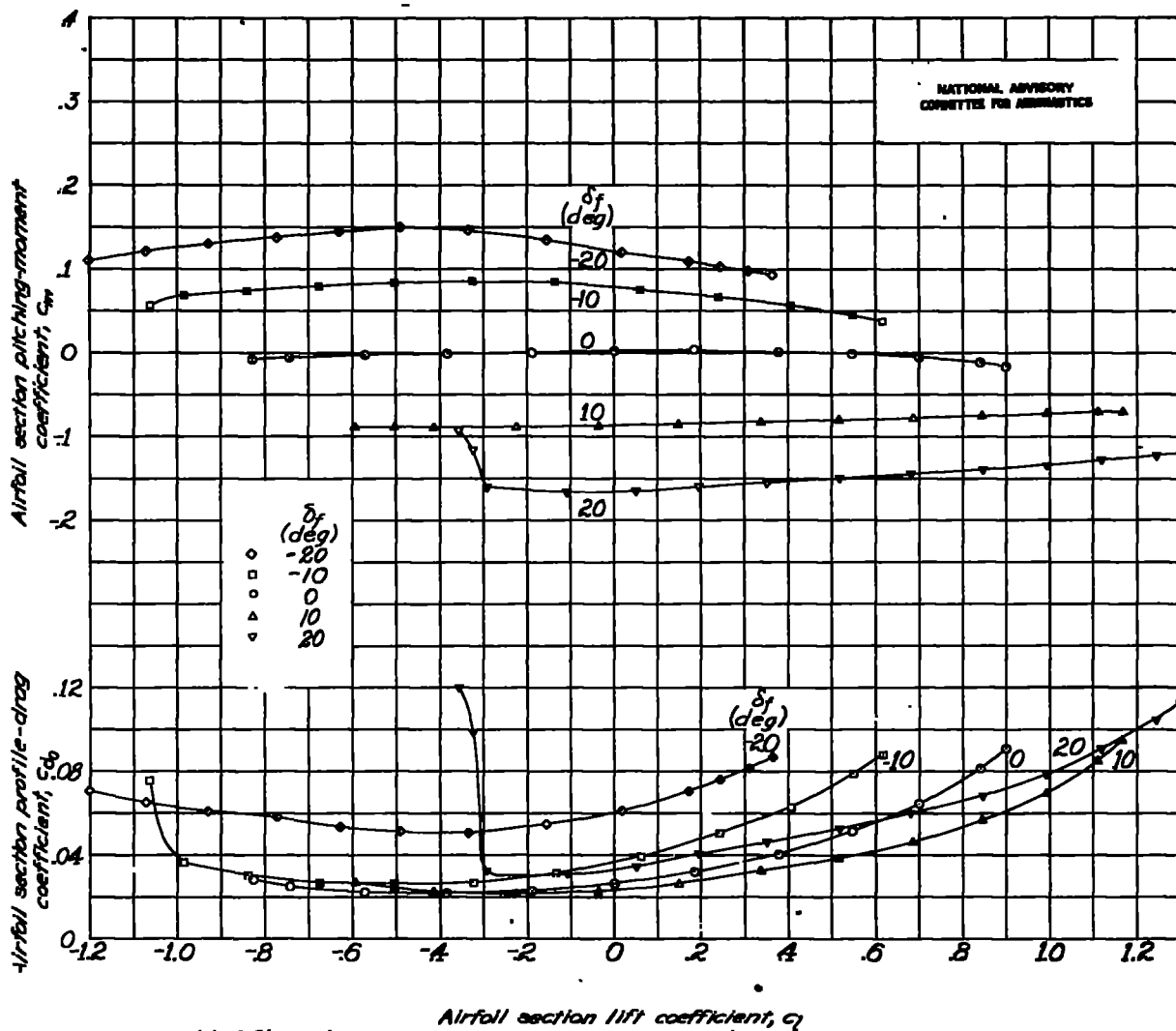
(a) 0.01c spoiler.
Figure 18.- Continued.
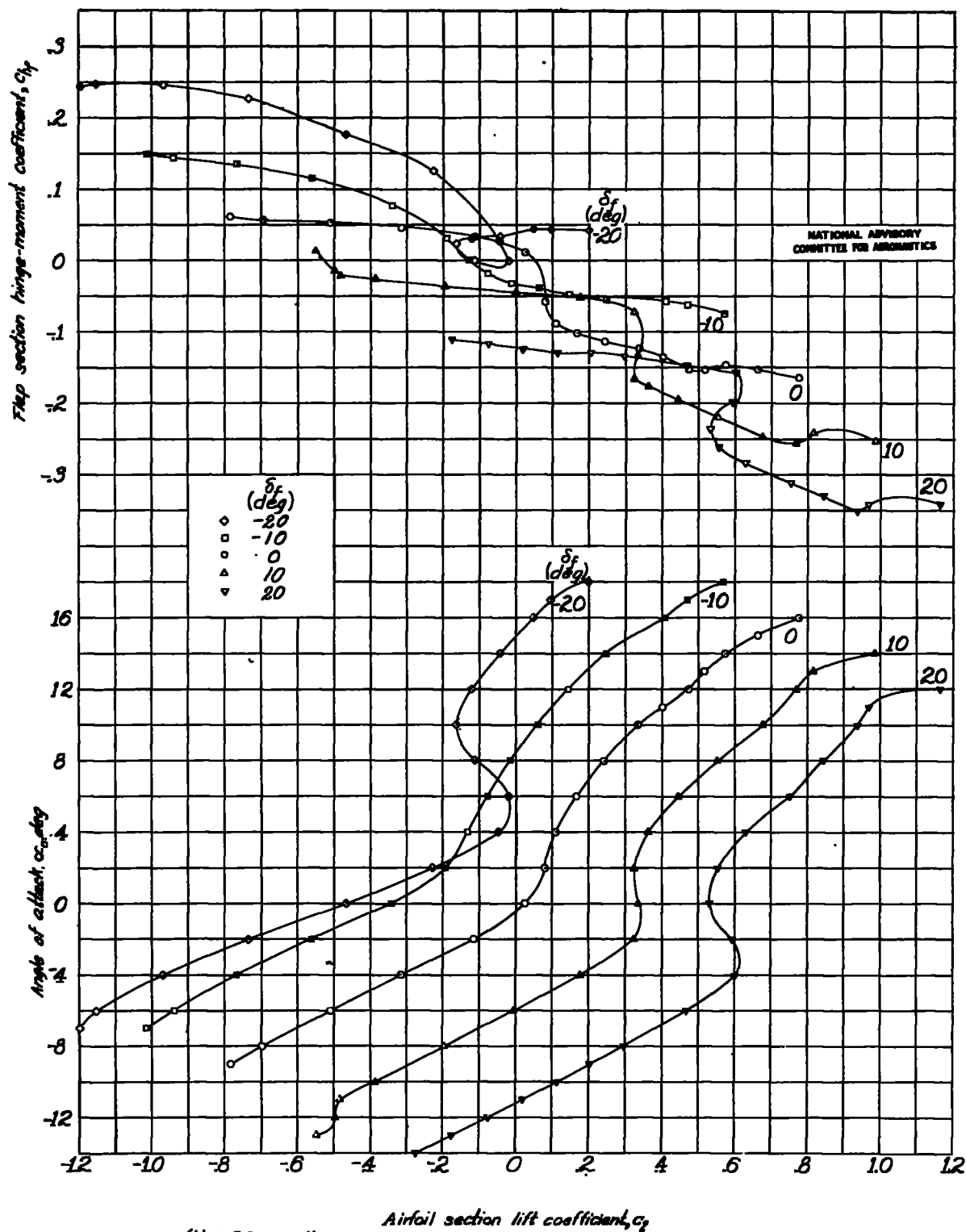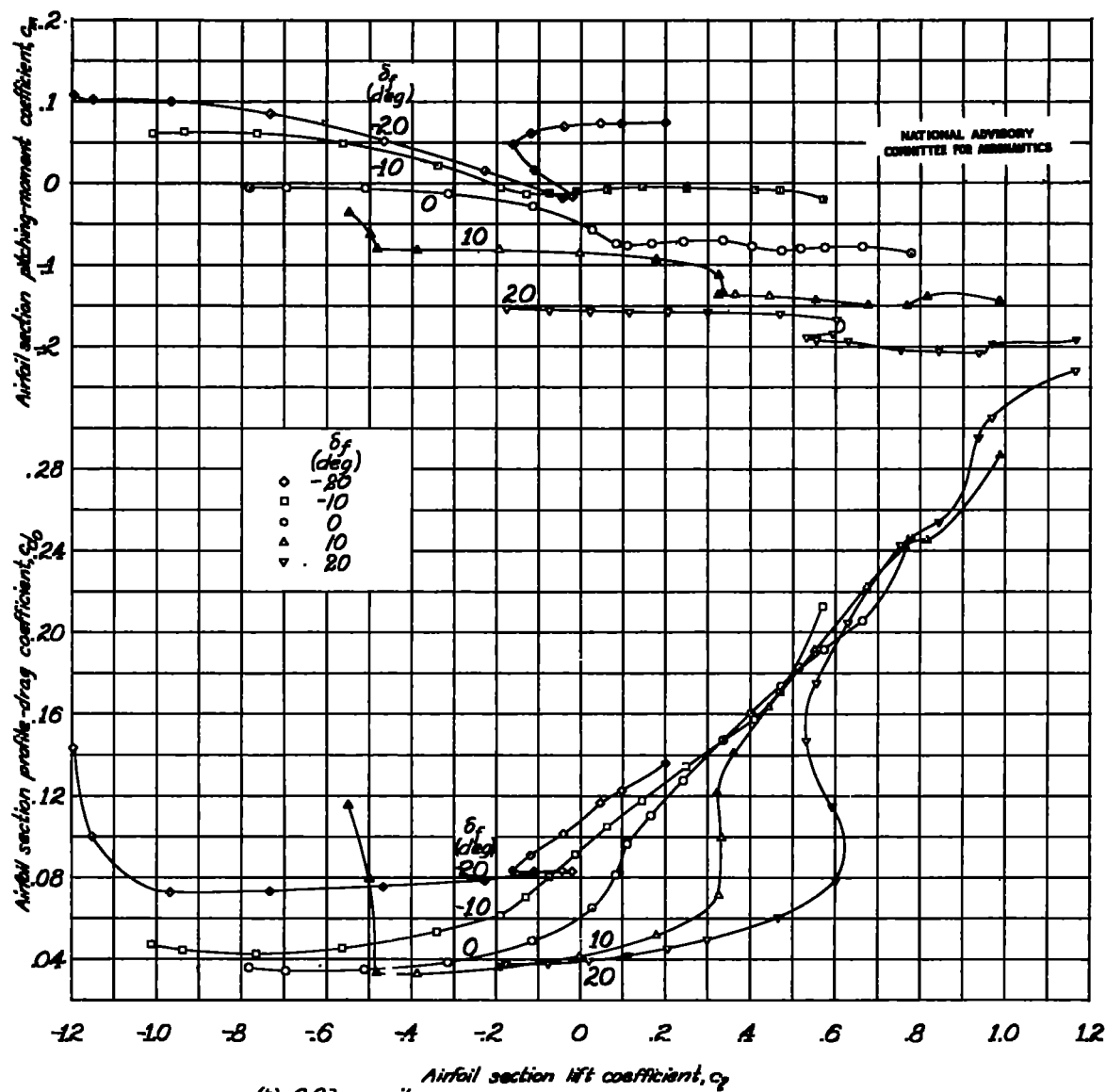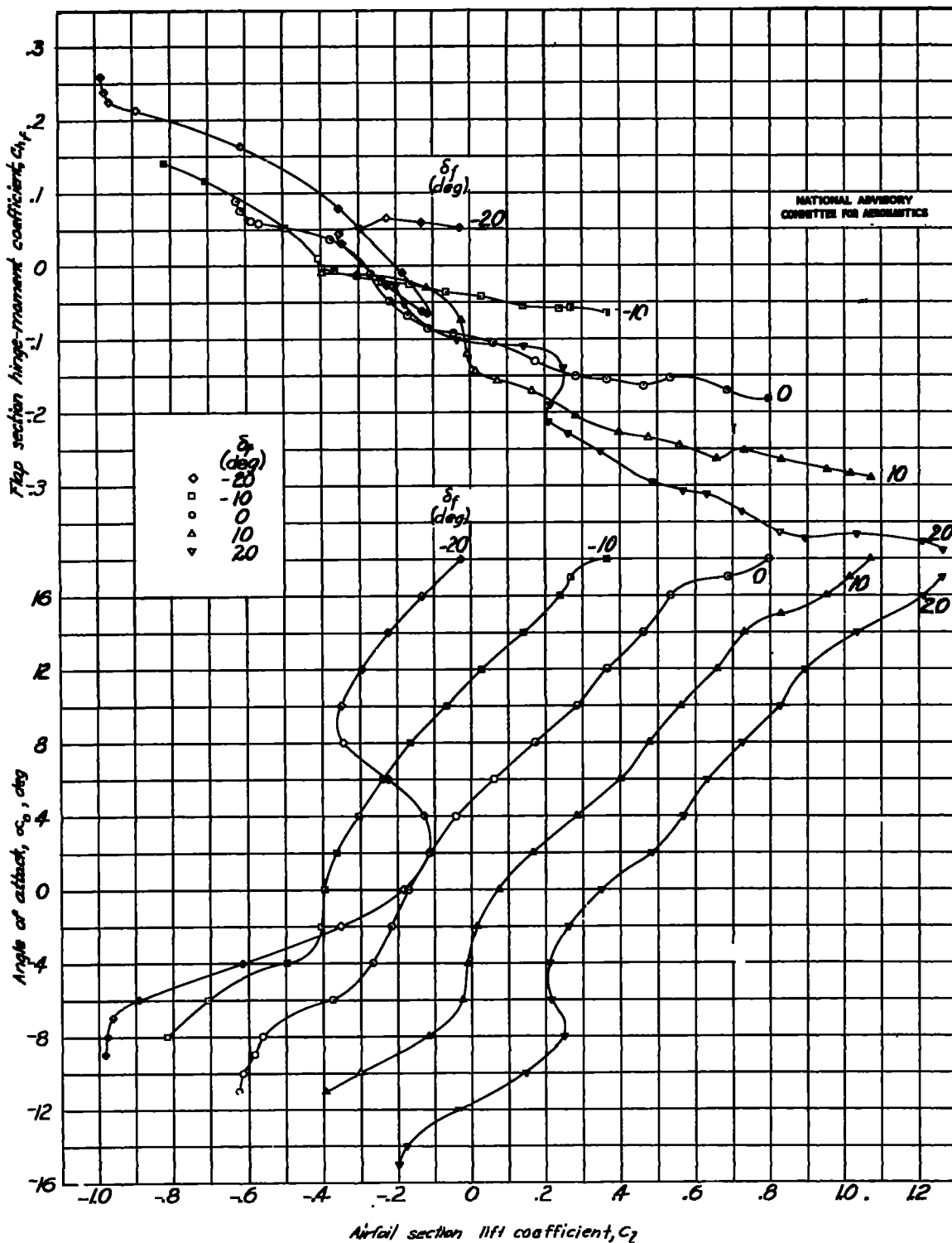
(b) 0.03c spoiler.
Figure 12.- Continued.

Airfoil section lift coefficient, c_l

(b) 0.03c spoiler.

Figure 12.- Continued.

(c) 0.06c spoiler.
Figure 12.- Continued.
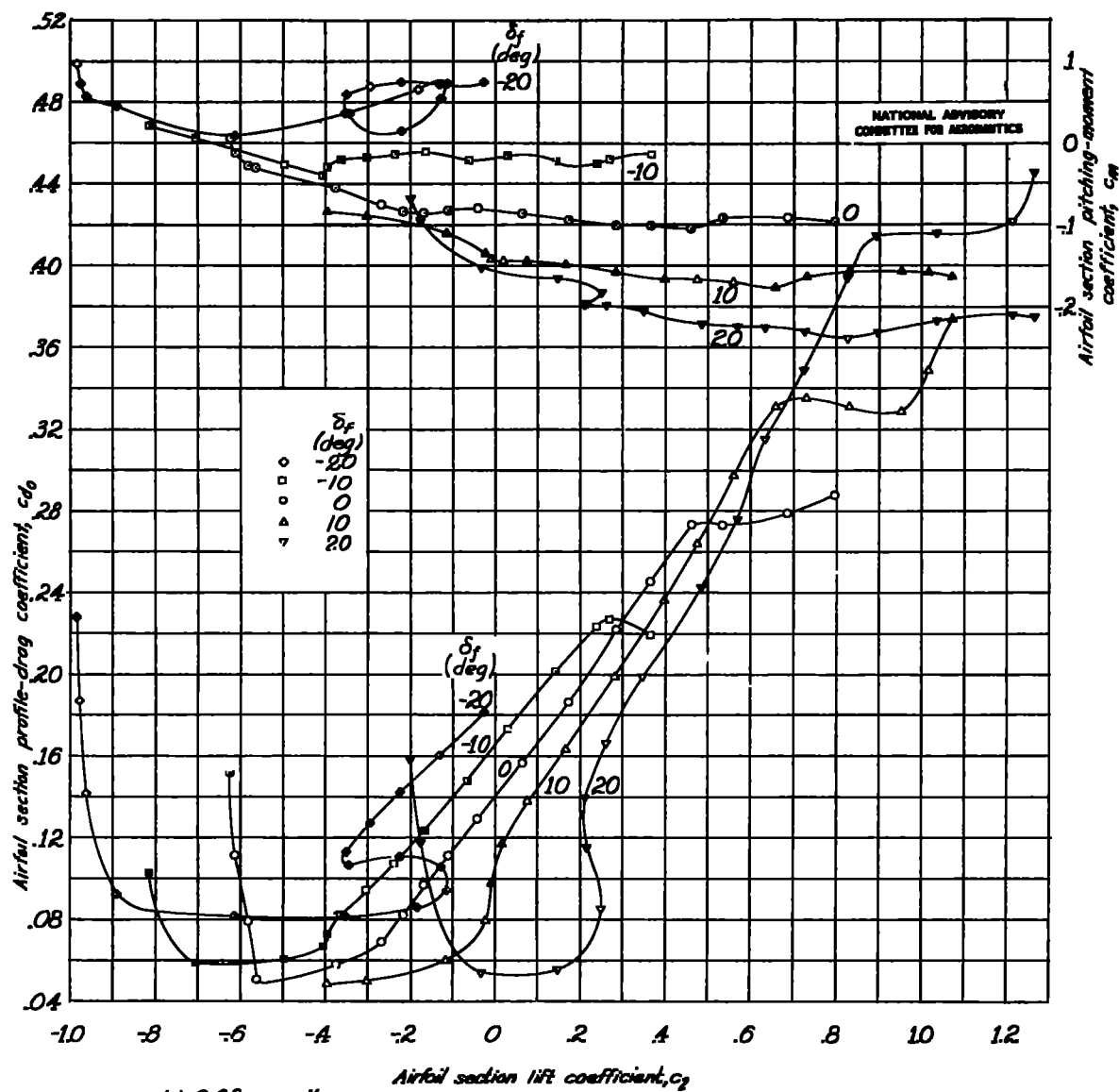
(c) 0.06c spoiler.
Figure 12.- Continued.

(d) 0.09c spoiler.

Figure 12.- Continued.
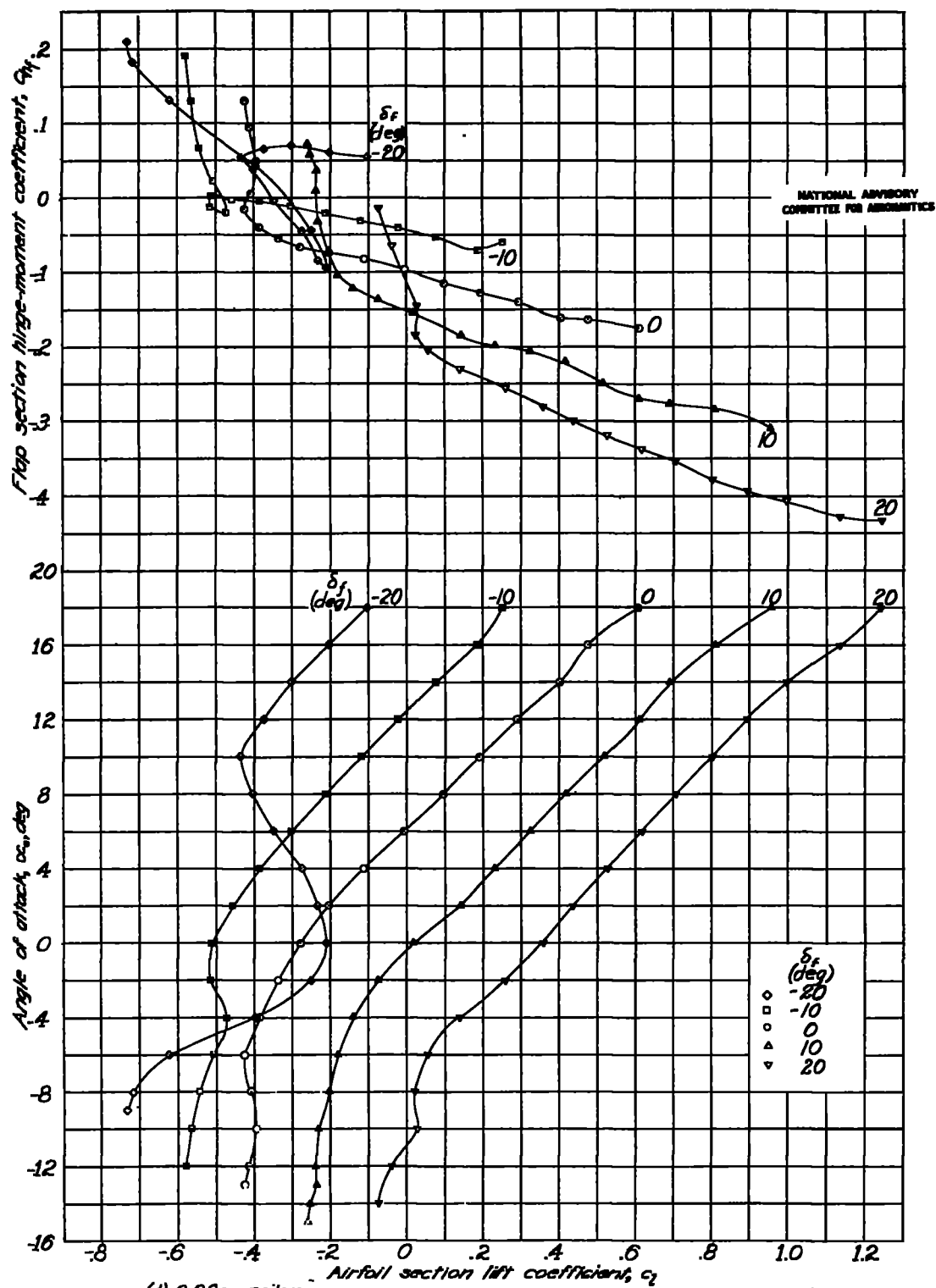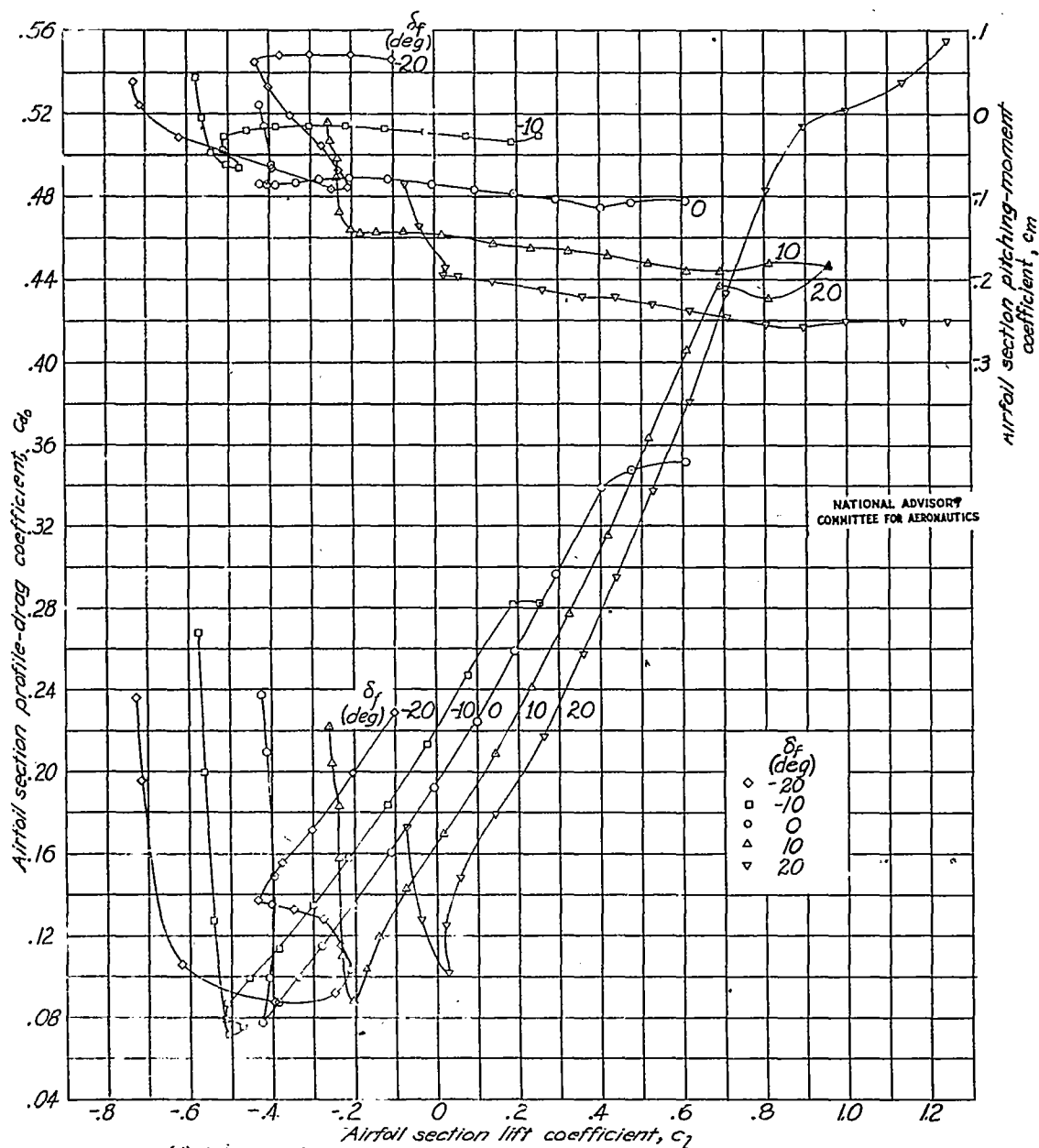
(d) 0.09c spoiler.

Figure 12.- Concluded.

(a) $\delta_f = 15°$.
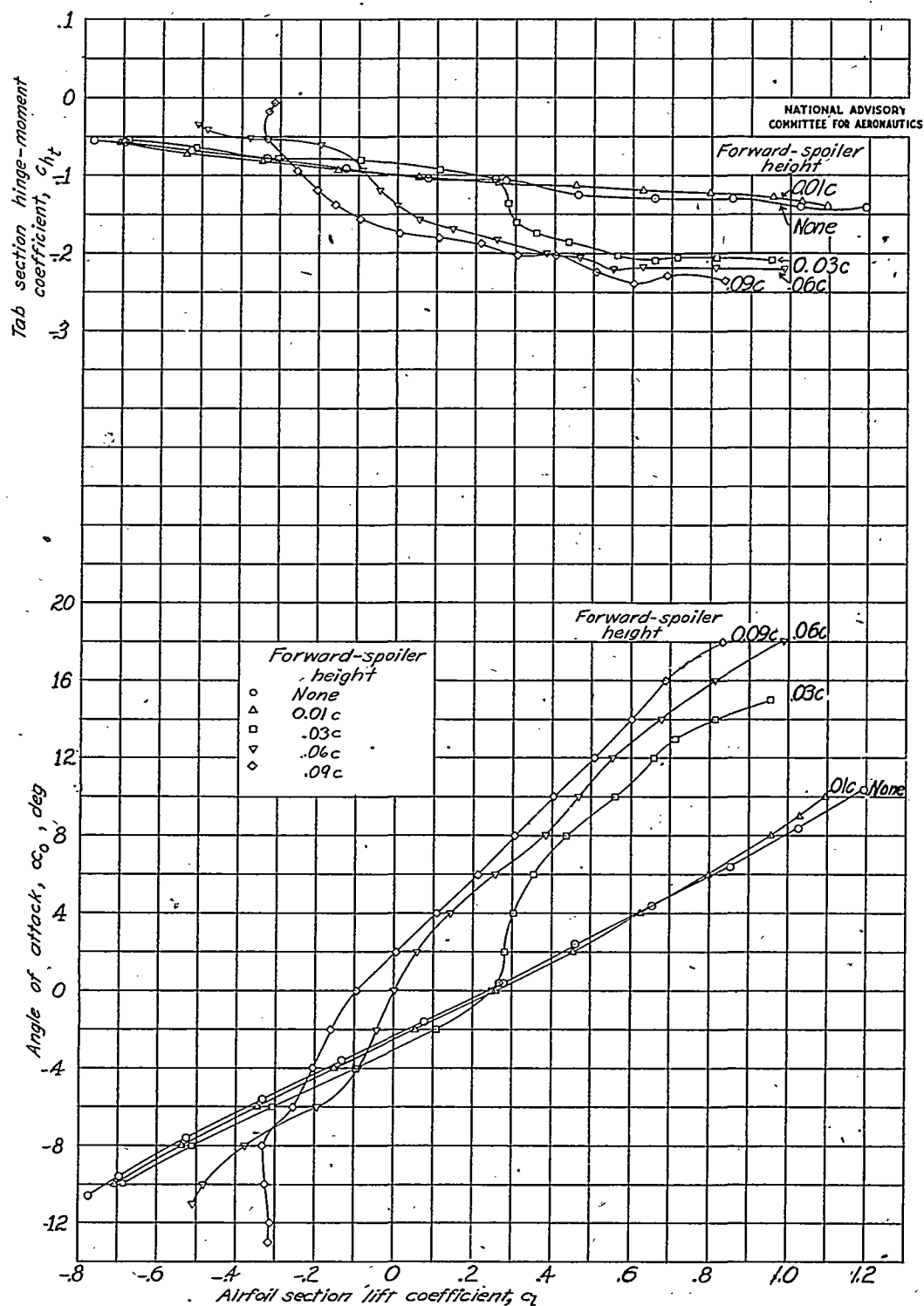
Figure 13.- Effect of forward-spoiler height, with constant tab deflection, on the aerodynamic section characteristics. Spoiler on upper surface at 0.15c. $\delta_f = 0°$.

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(a) $\delta_f = 15°$.
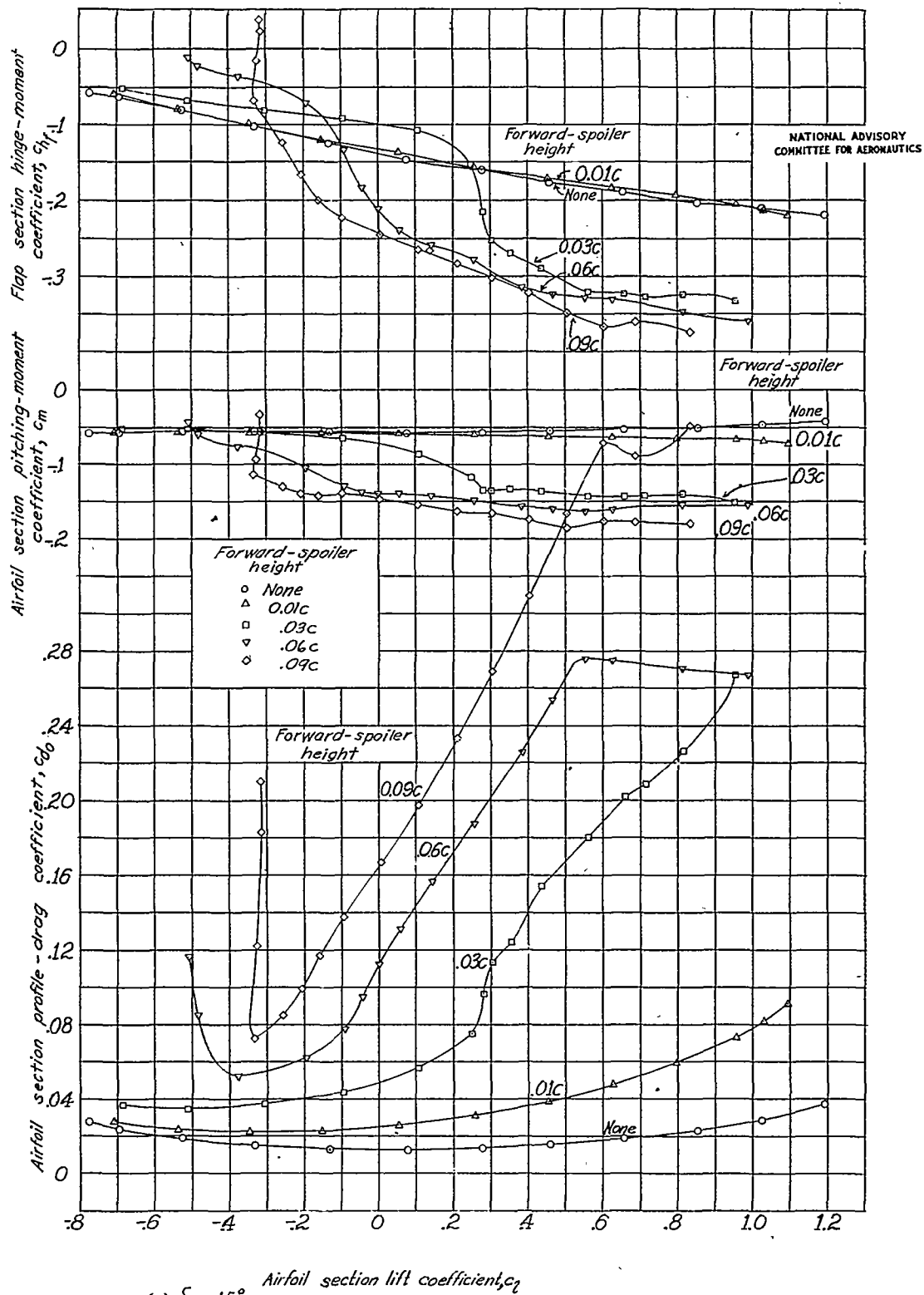
Figure 13.- Continued.
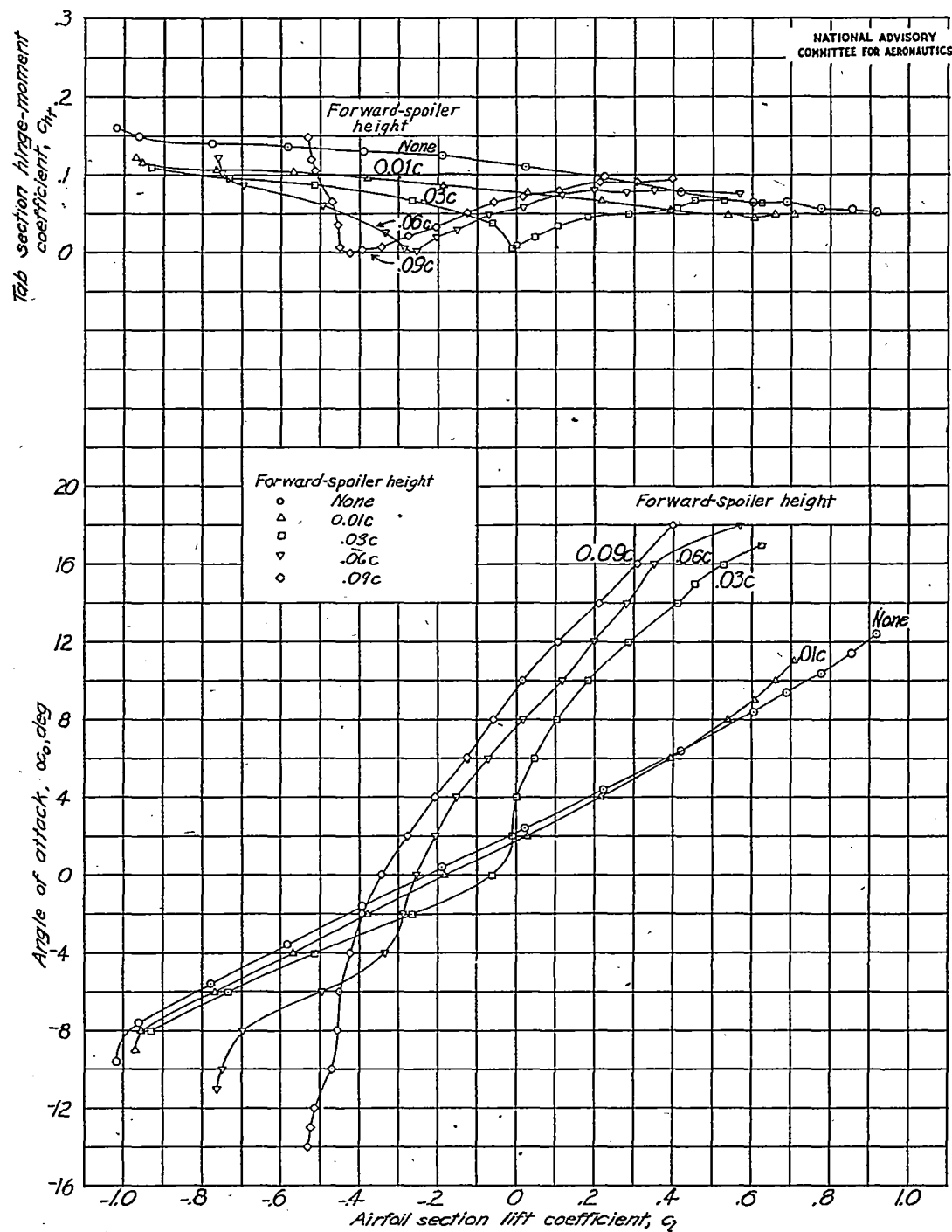
(b) $\delta_t = -15°$.
Figure 13.- Continued.
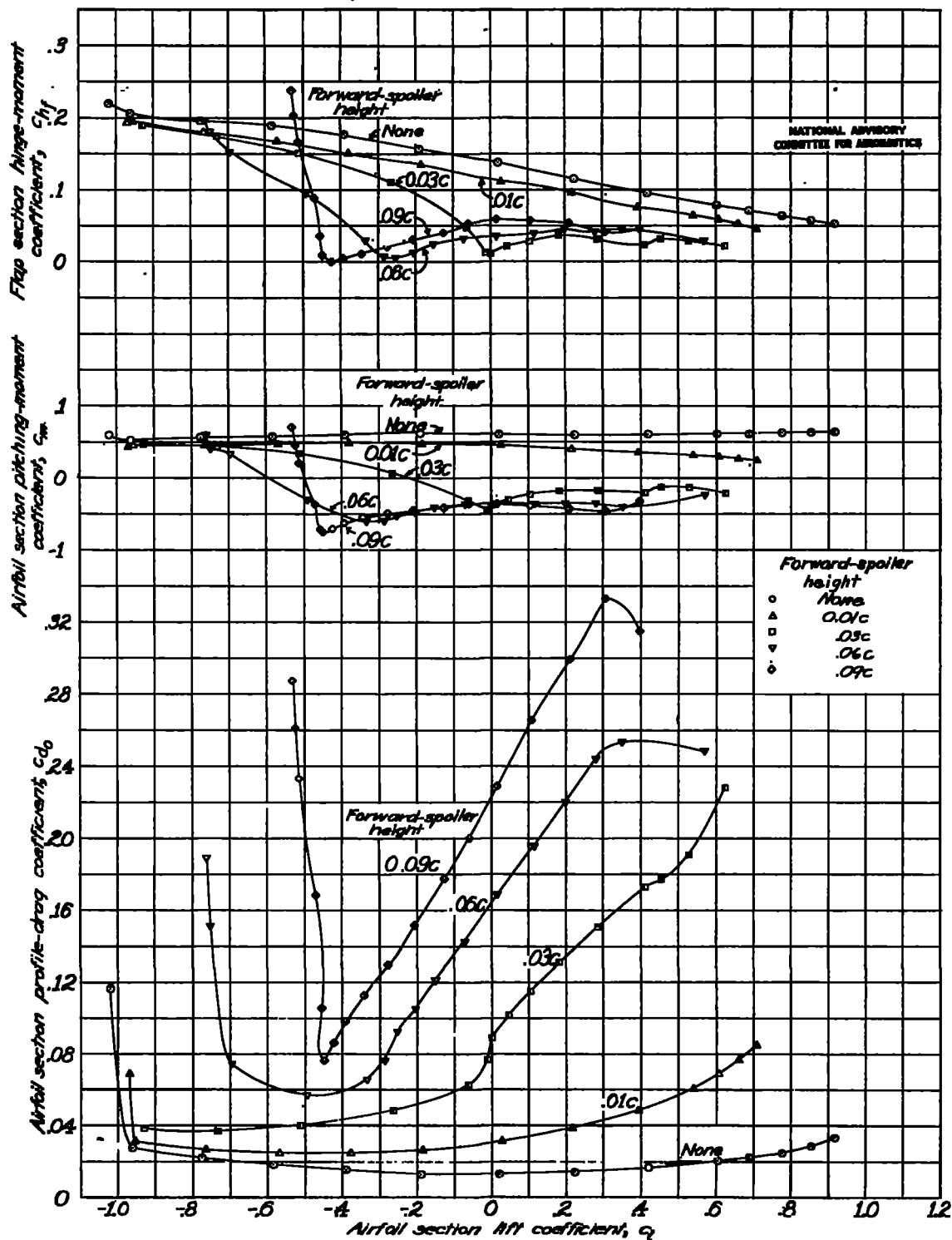
(b) $\delta_f = -15°$.
Figure 13.- Concluded.

(a) 0.0/c forward spoiler.

Figure 14.- Effect of rear-spoiler height on the aerodynamic section characteristics with a rear spoiler at 0.65c and with a constant-height spoiler at 0.15c; both spoilers on the upper surface of the airfoil; $\delta_f - \delta_s = 0.°$

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Rear-spoiler
height
0.15c
.10c
.05c
None

Rear-spoiler
height
o   None
□   0.05 c
▼   .10 c
◇   .15 c

Rear-spoiler
height
0.15c
.10c
.05c
None

(b) 0.03c forward spoiler.
Figure 14.- Continued.

(c) 0.06c forward spoiler.

Figure 14.- Continued.

Airfoil section pitching-moment coefficient, c_m

Angle of attack, α_o, deg

Airfoil section profile-drag coefficient, c_{d_o}

Rear-spoiler height

None

c_{d_o}

0.10c

.15c

Rear-spoiler height

None

0.10c

.15c

Rear-spoiler height
- None
- 0.10c
- .15c

Airfoil section lift coefficient, c_l
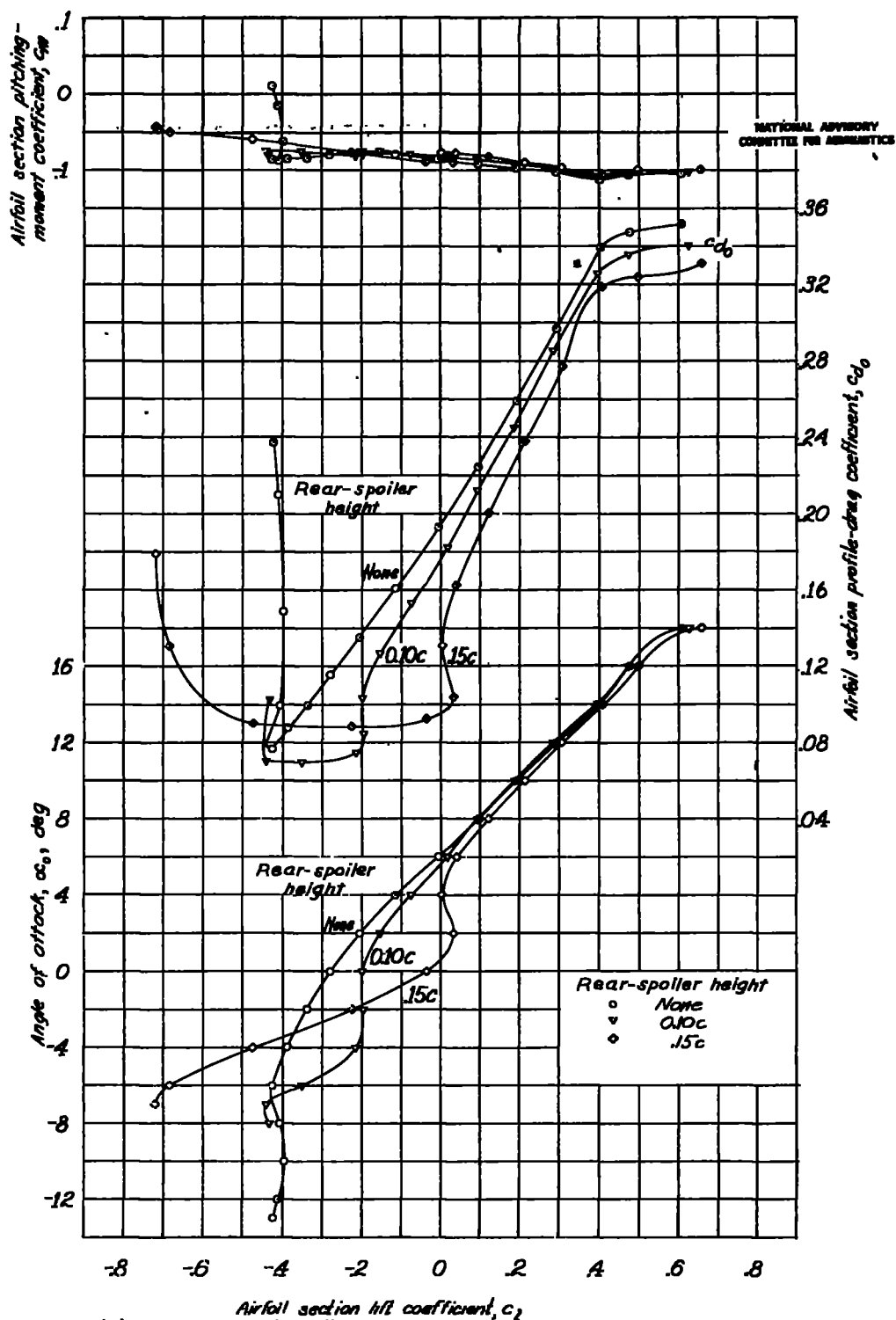
(d) 0.09c forward spoiler

Figure 14.- Concluded.

(a) 0.01c forward spoiler.

Figure 15.-Effect of rear-spoiler height on the aerodynamic section characteristics with a rear spoiler at 0.65c on lower surface and with a constant-height spoiler at 0.15c on upper surface of the airfoil; $\delta_f = \delta_t = 0°$.
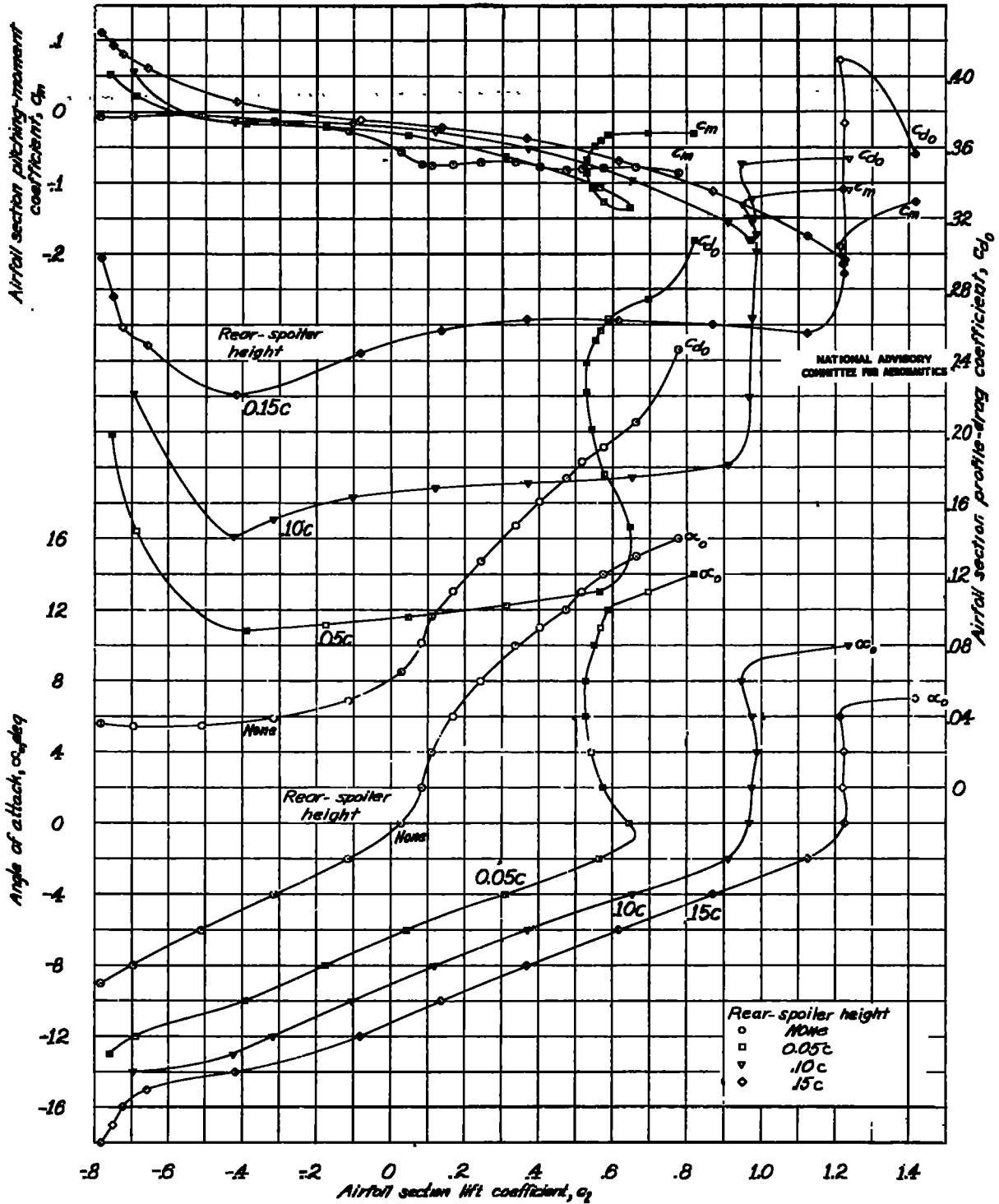
(b) 0.03 c forward spoiler.
Figure 15.—Continued.
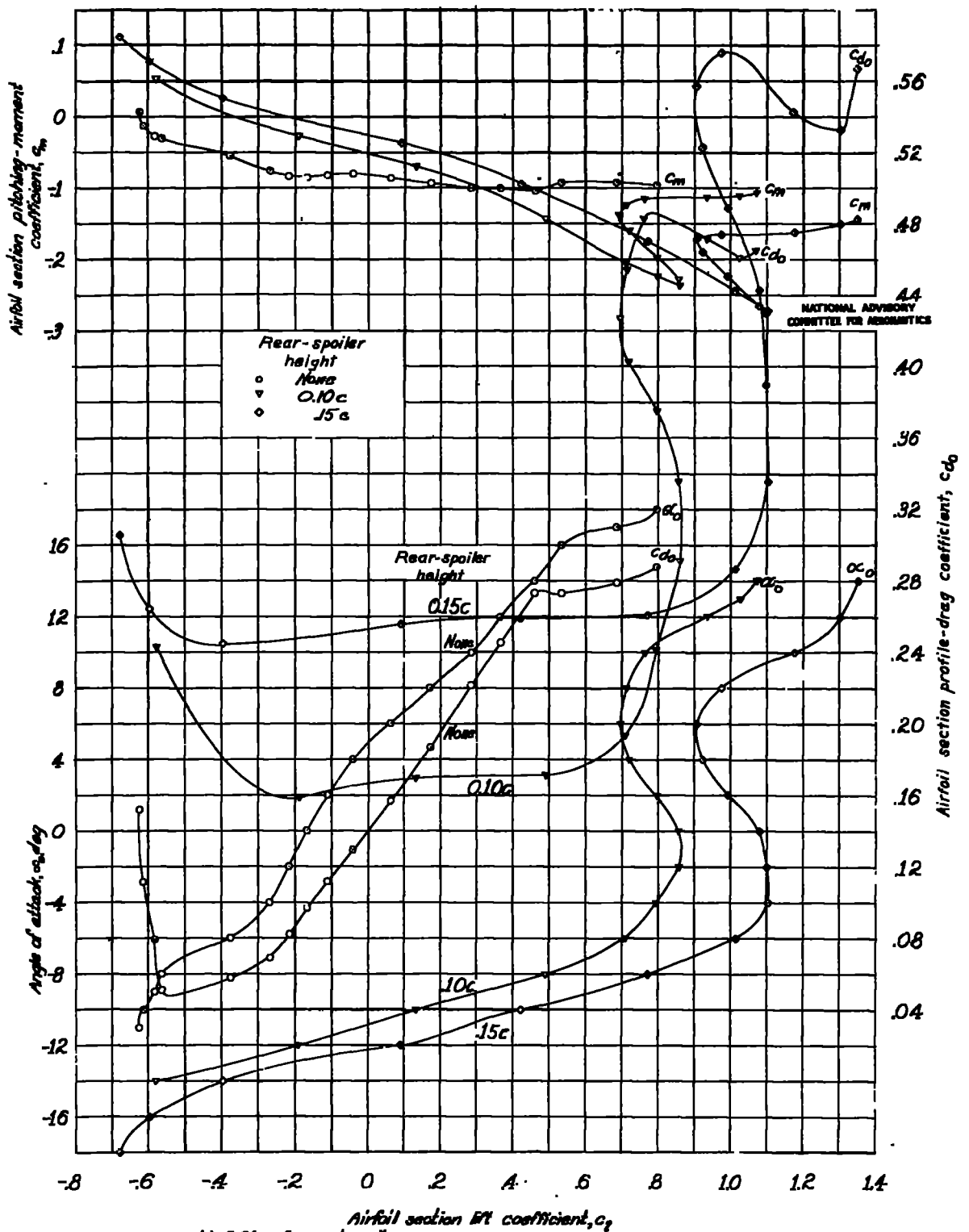
(c) 0.06c forward spoiler.

Figure 15.- Continued.
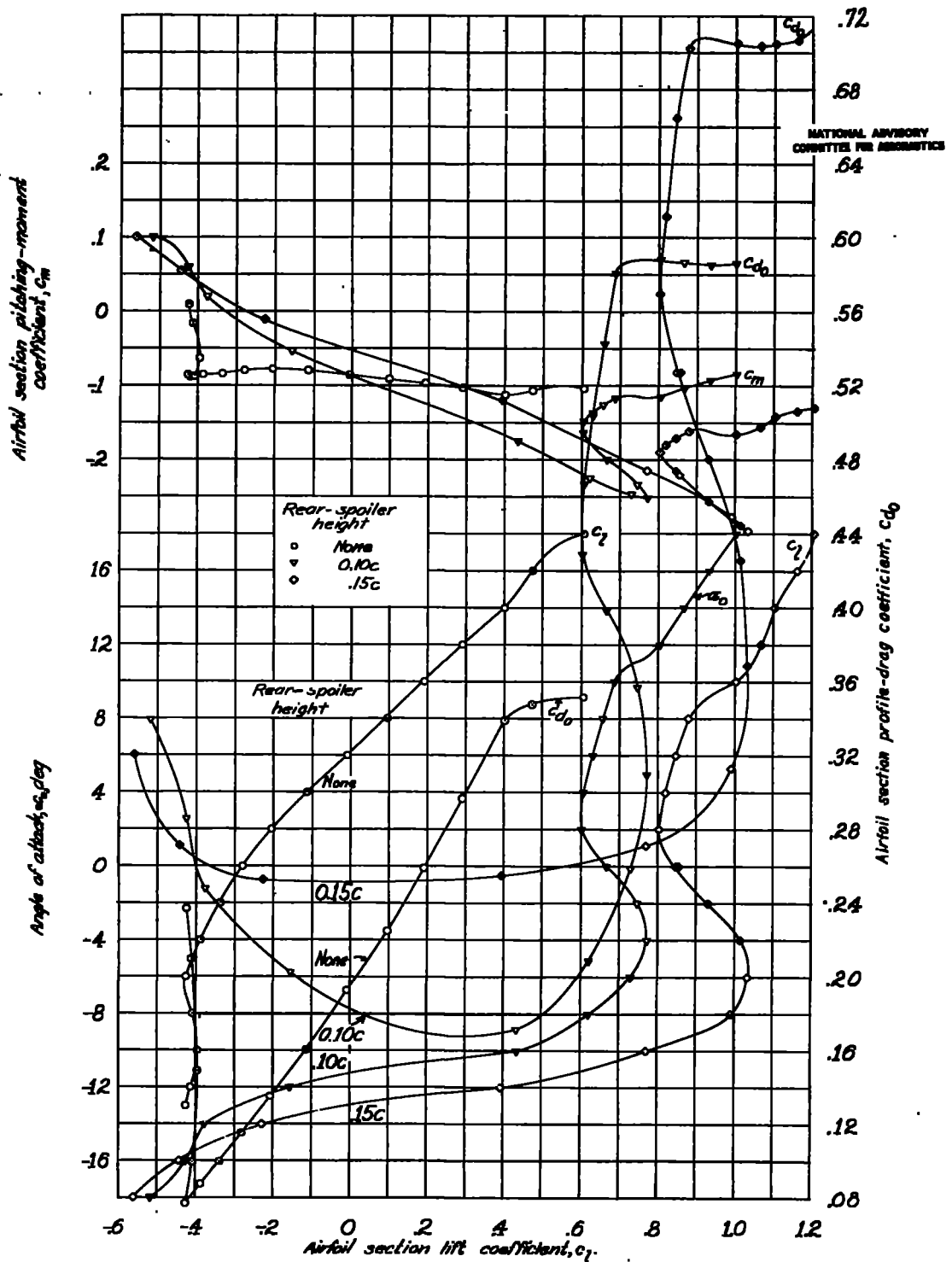
(d) 0.09c forward spoiler.
Figure 15.- Concluded.

Fig. 16   NACA ARR No. L5F28
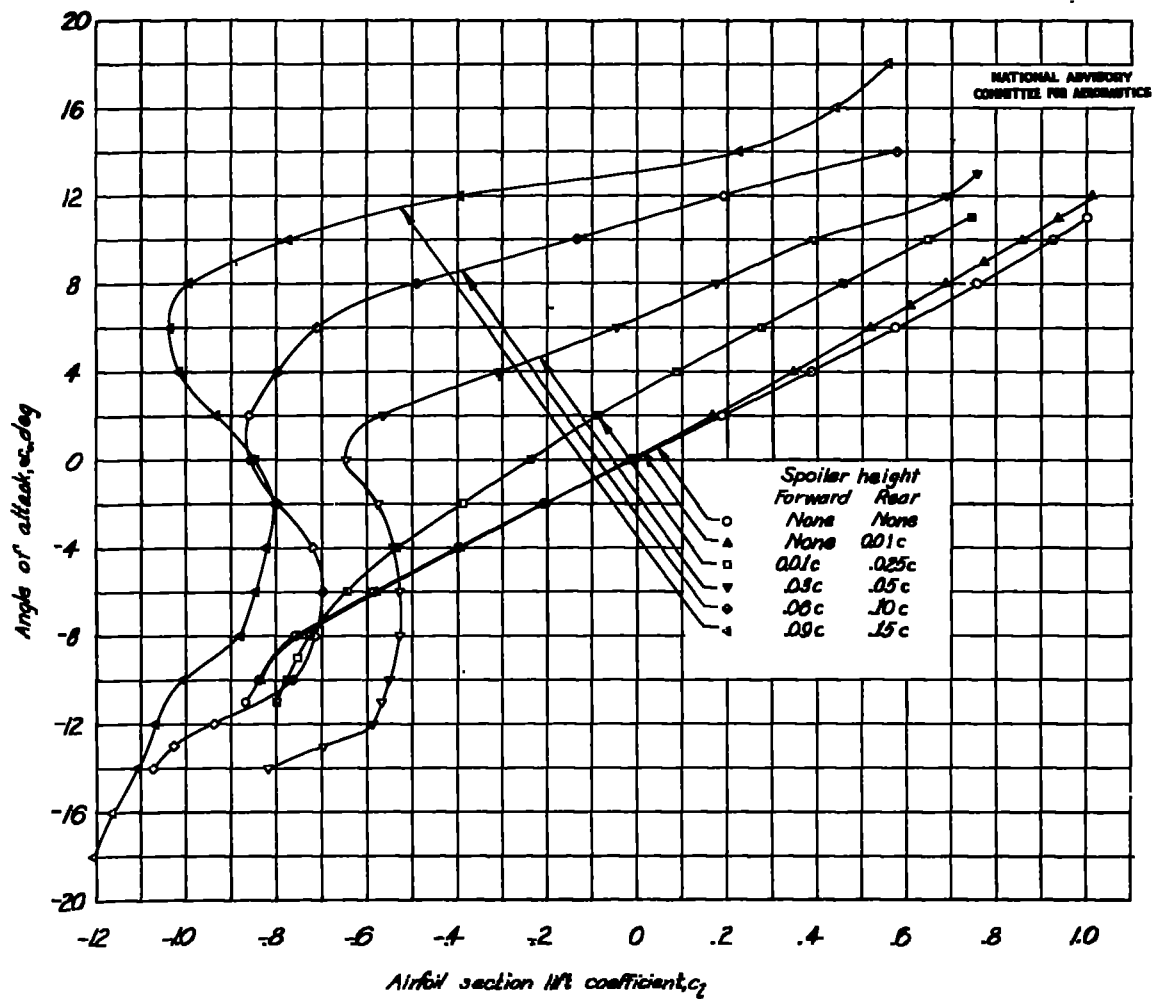
Figure 16.—Effect of double spoilers on the aerodynamic section characteristics. Forward spoiler on the lower surface at 0.15c and rear spoiler on the upper surface at 0.65c. $\delta_f = \delta_t = 0°$.

Figure K.- Concluded.

Fig. 17   NACA ARR No. L5F28
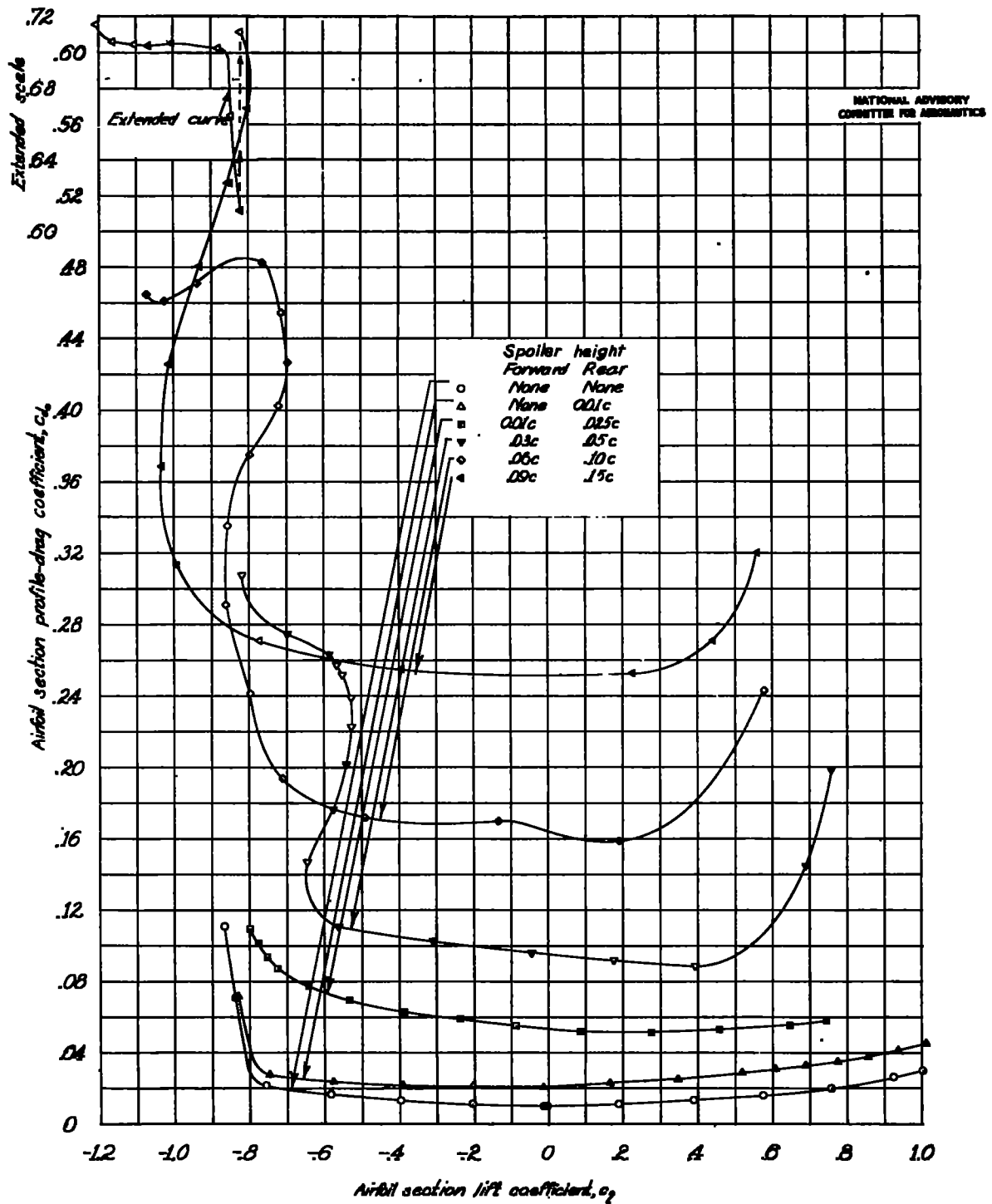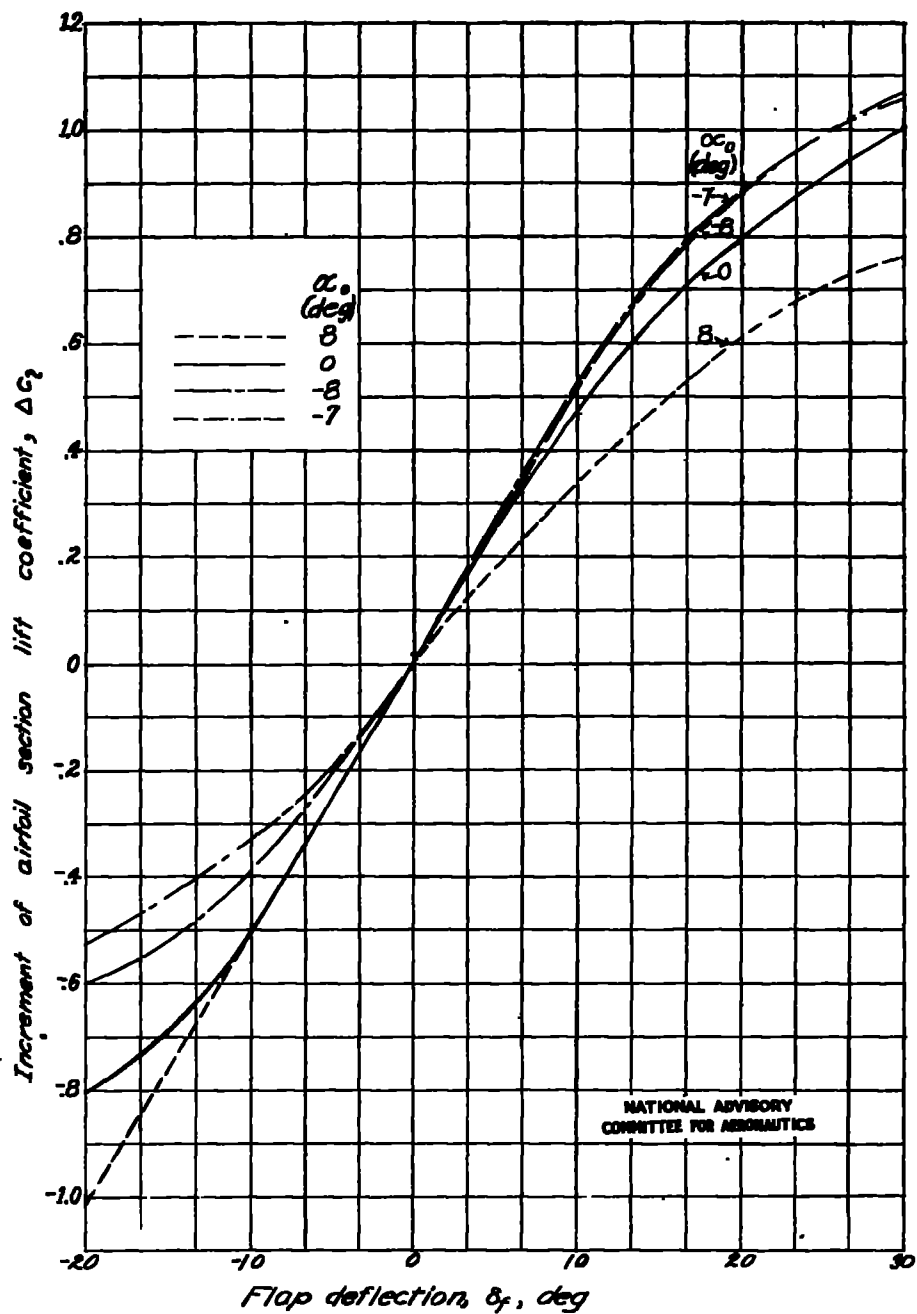
Figure 17.- Effect of flap deflection on Δc_l and Δc_{h_f} with no spoilers on the plain airfoil.

Fig. 17 Conc.

Increment of flap section hinge-moment coefficient, Δc_{h_f}

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Flap deflection, δ_f, deg

Figure 17.- Concluded.

Fig. 18   NACA ARR No. L5F28
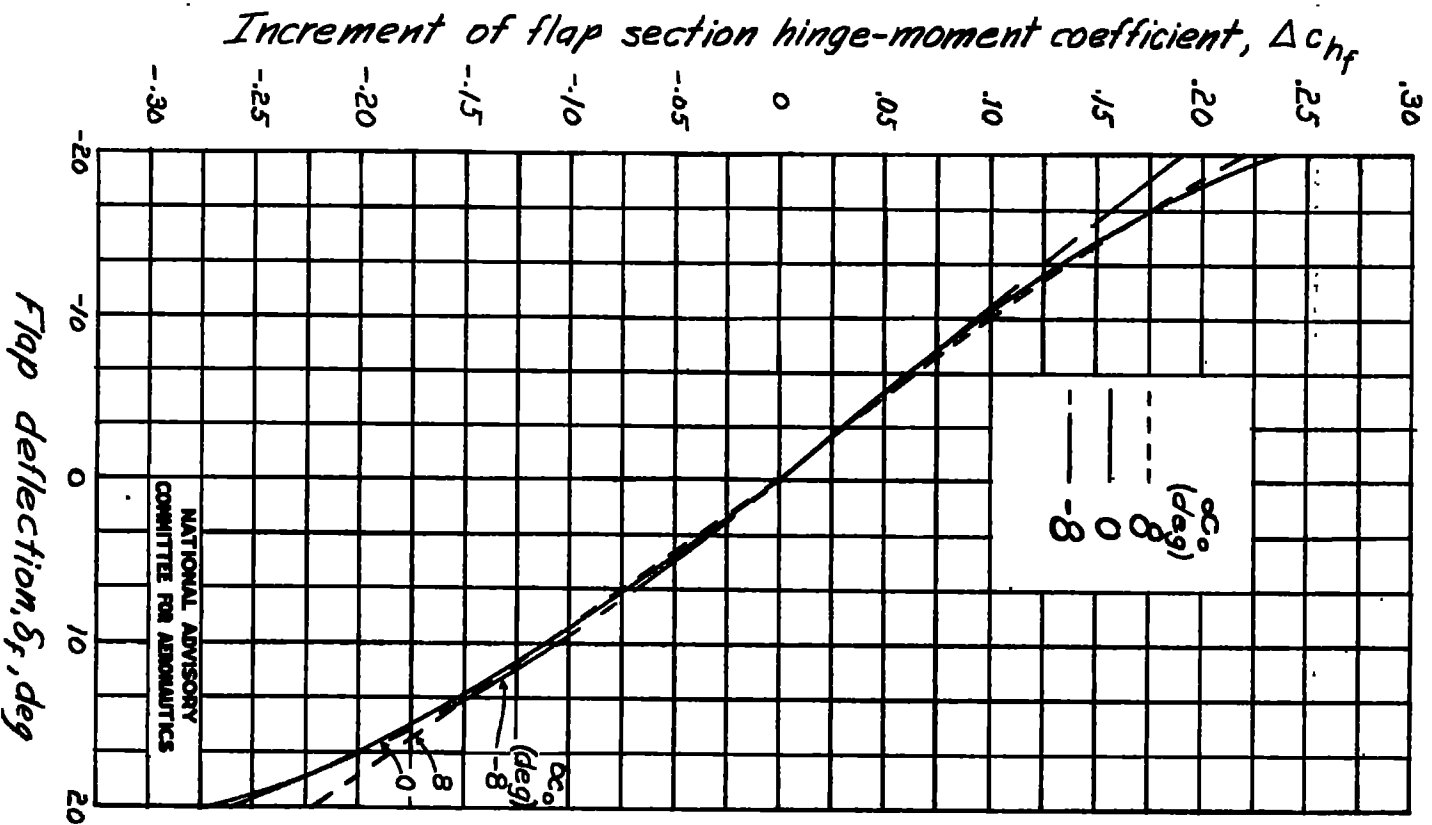
Rear-spoiler projection, δ_{S_R}, percent c
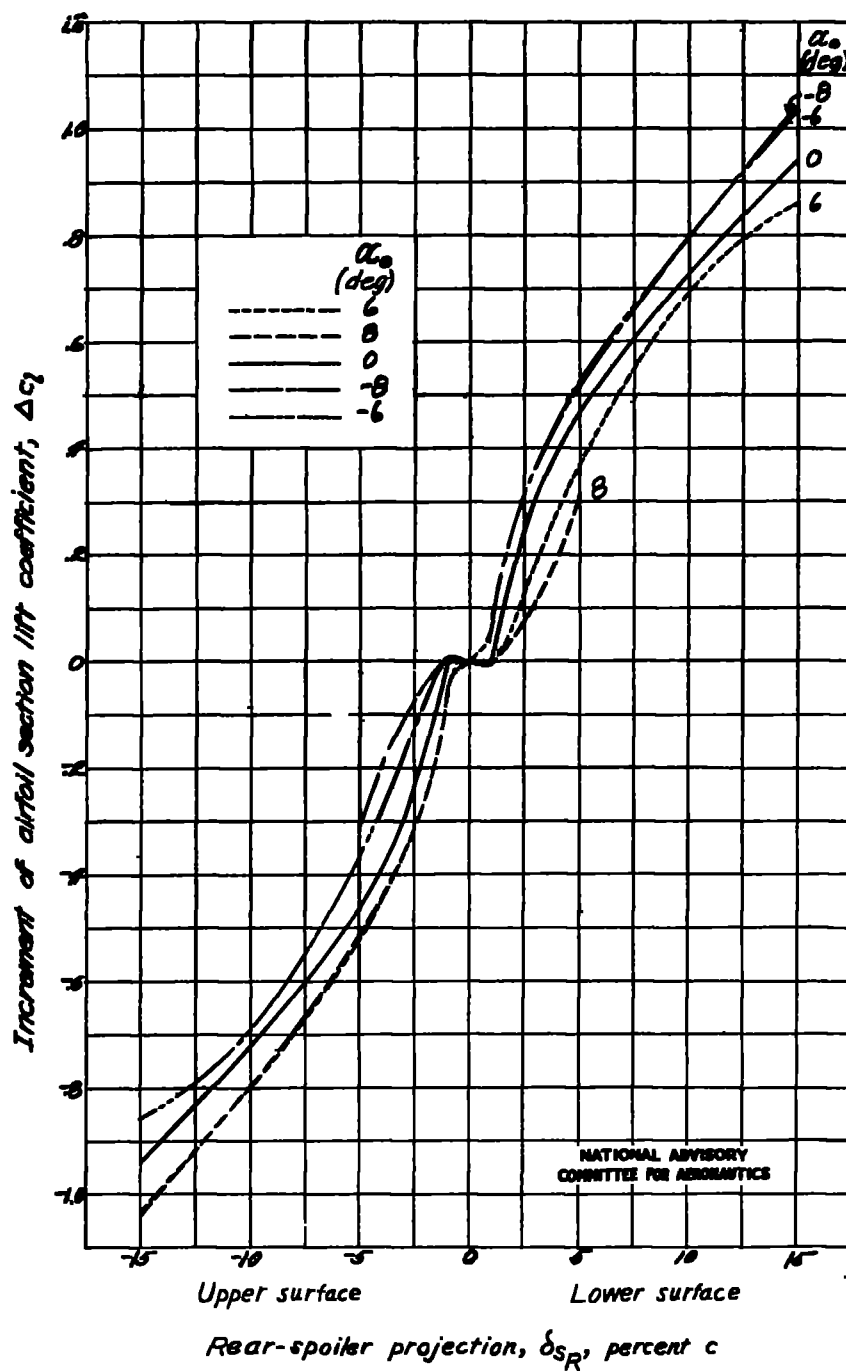
Figure 18.- Effect of rear-spoiler projection on Δc_l. $\delta_f = \delta_t = 0°$.
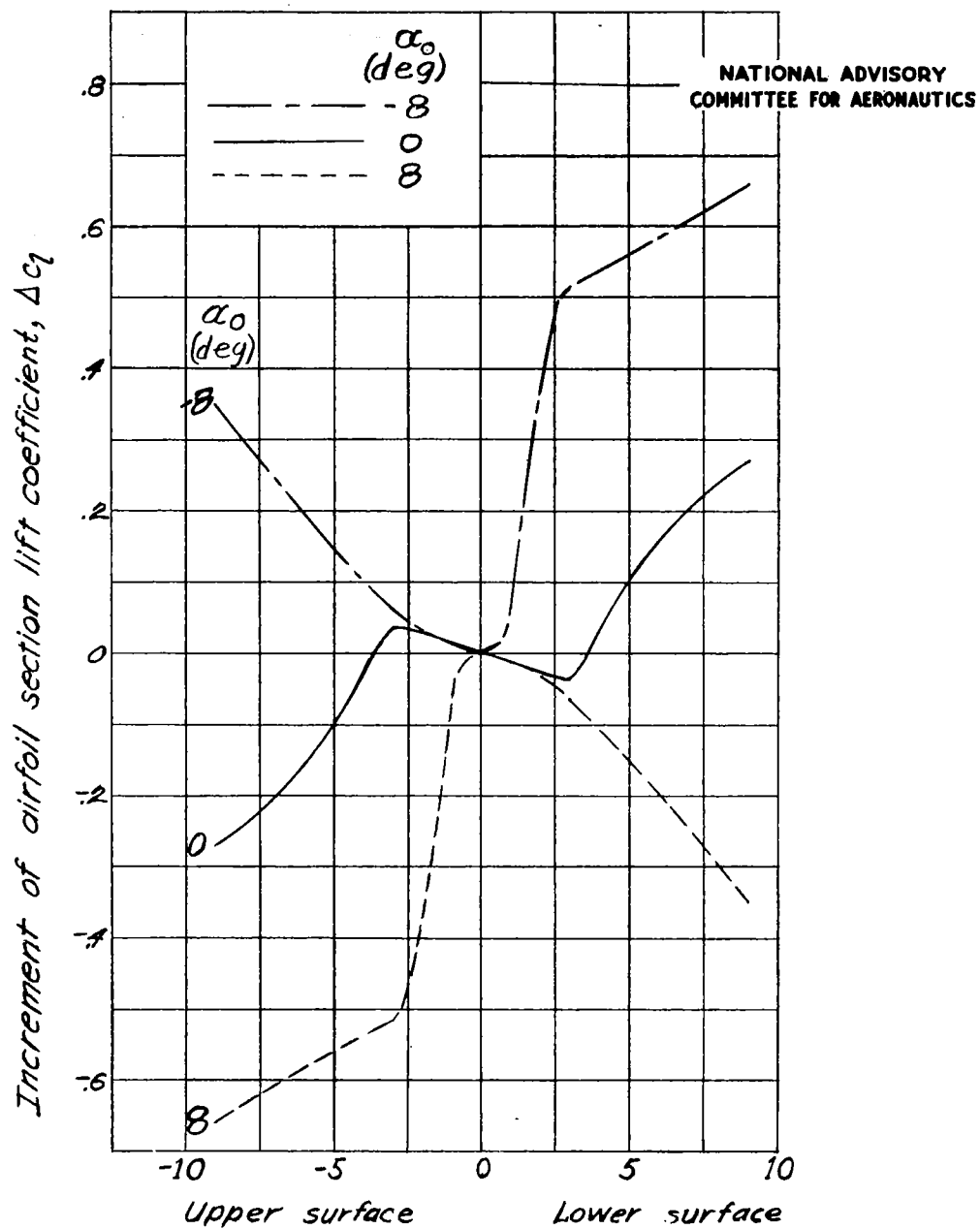
Figure 19.- Effect of forward-spoiler projection on Δc_l and Δc_{h_f}. $\delta_f = \delta_t = 0°$.

Fig. 19 Conc.   NACA ARR No. L5F28
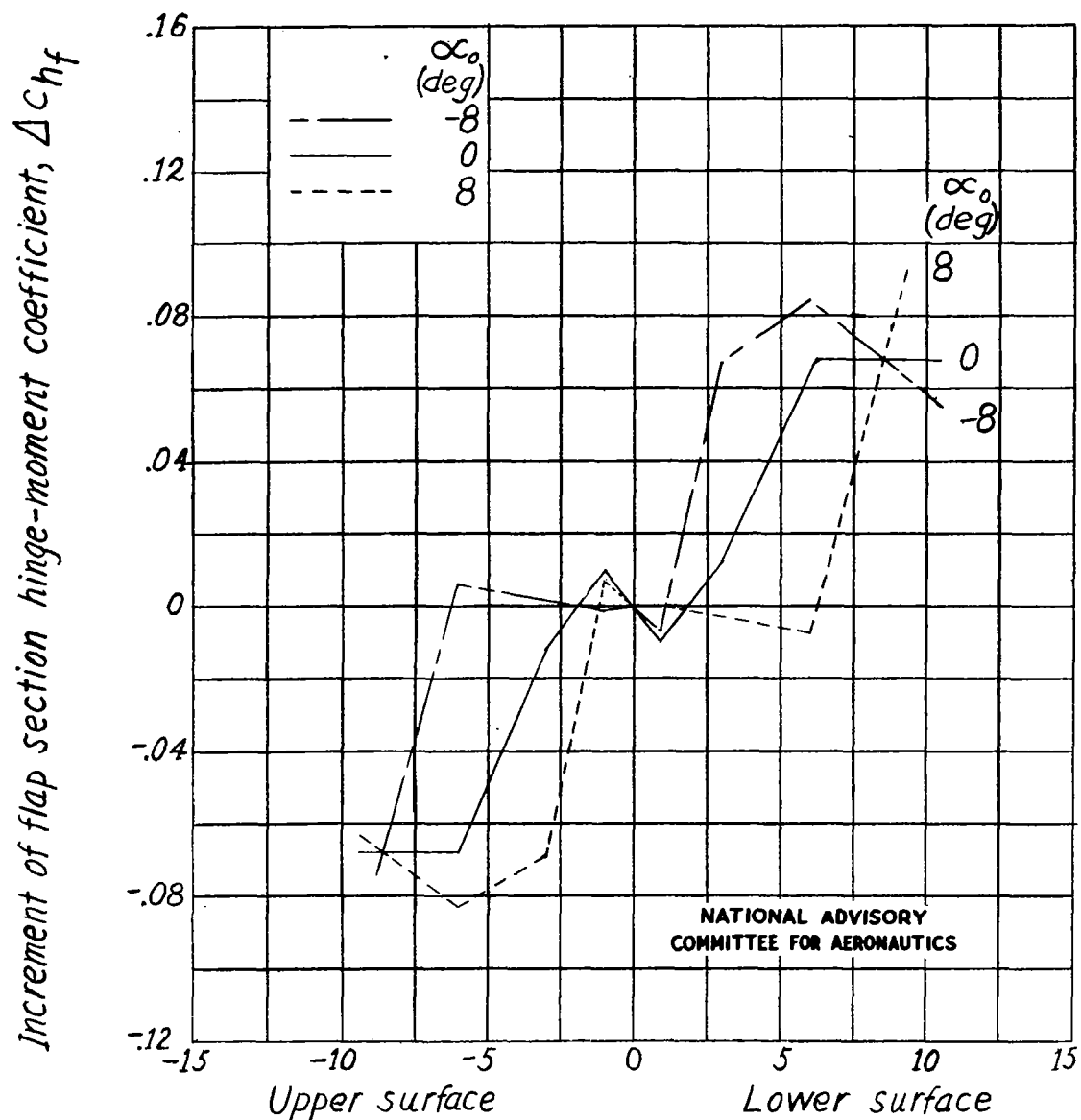
Forward-spoiler projection, δ_{SF}, percent c

Figure 19.—Concluded.
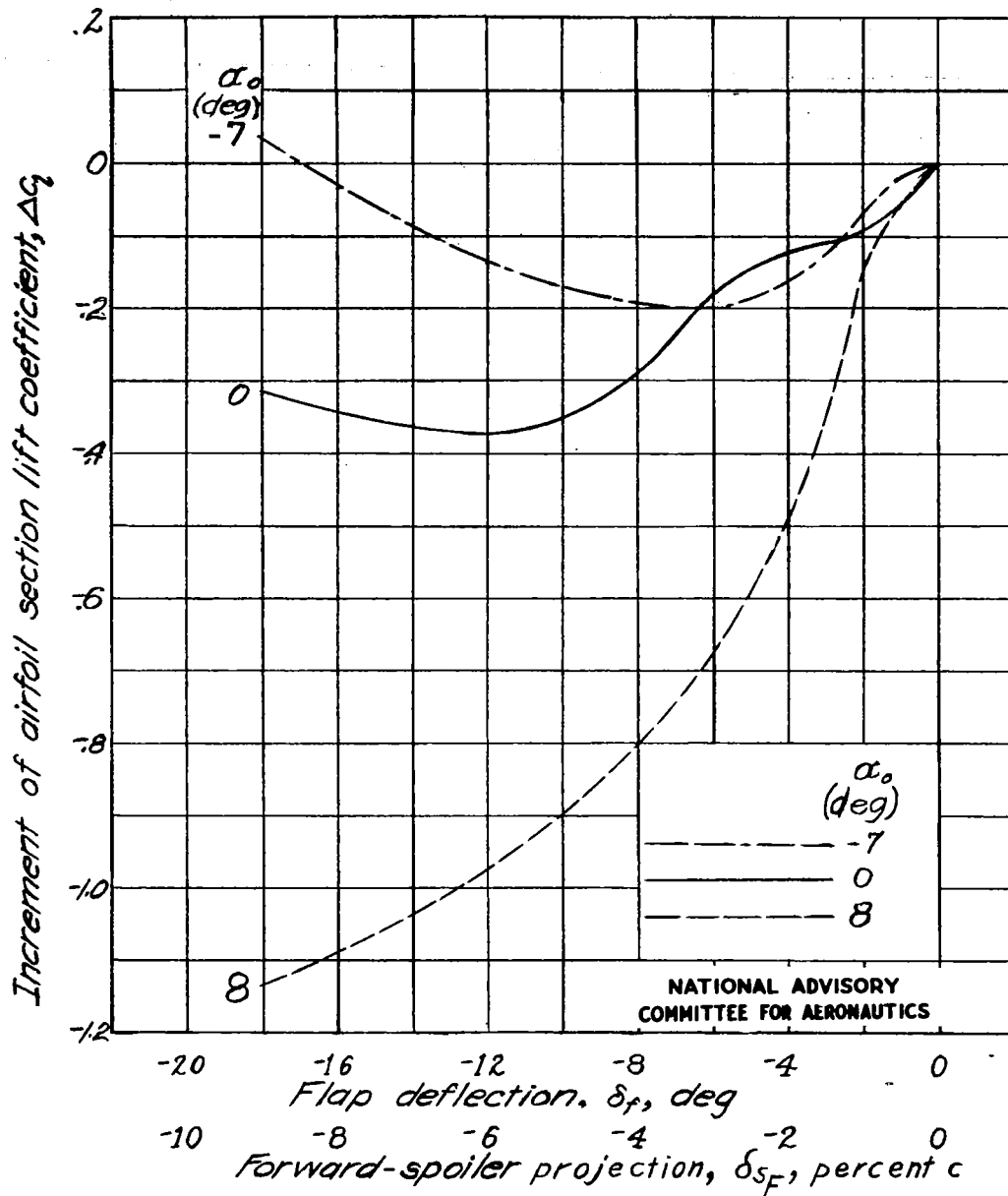
Figure 20.-Effect of forward-spoiler projection and flap
   deflection on Δc_l with spoiler projecting 0.05c while
   flap deflects 10°; spoiler on upper surface and
   flap deflecting upward.

Fig. 21   NACA ARR No. L5F28
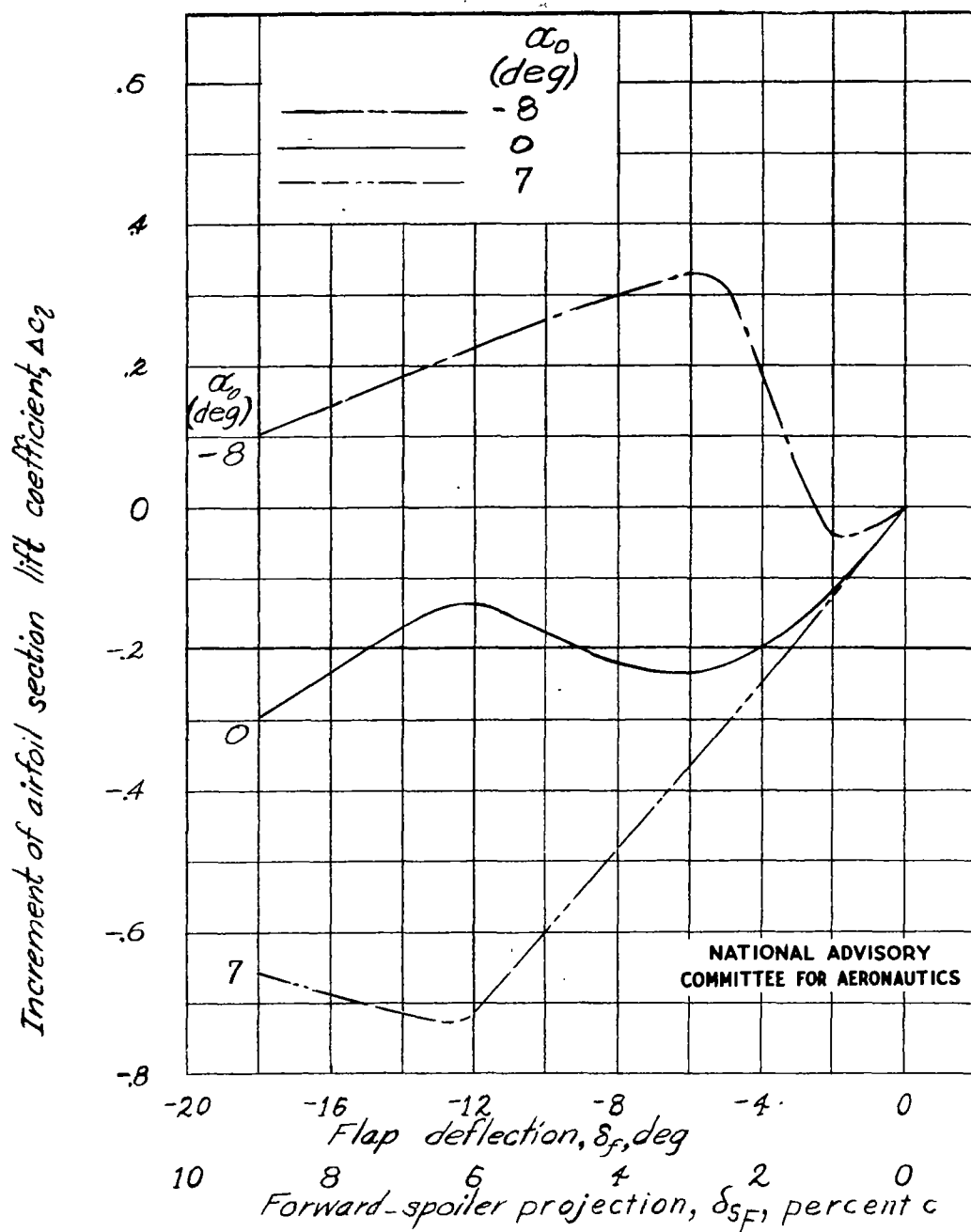
Figure 21.- Effect of forward-spoiler projection and flap deflection on Δc_l with spoiler projecting 0.05c while flap deflects 10°. Spoiler on lower surface and flap deflecting upward.
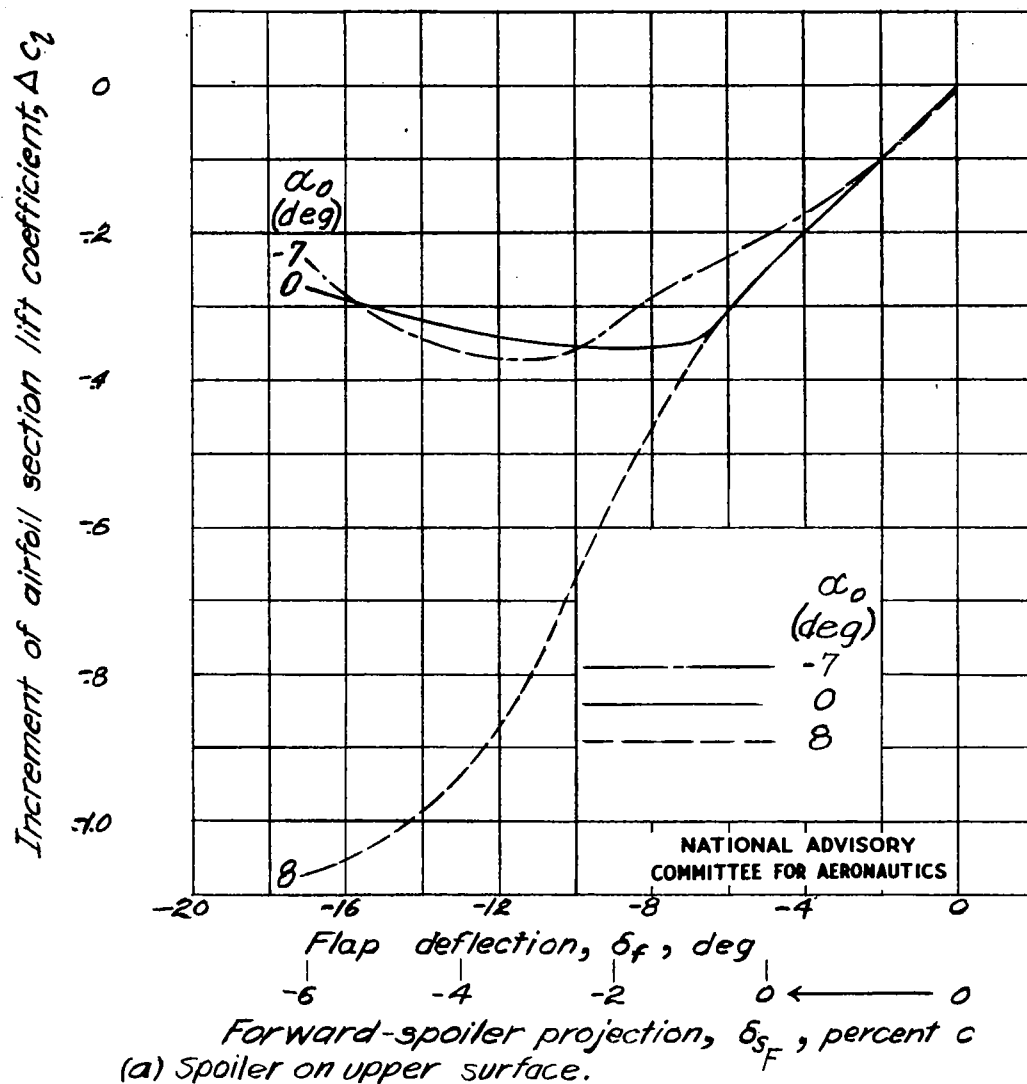
(a) Spoiler on upper surface.

Figure 22.-Effect of forward-spoiler projection and flap
  deflection on Δc_l with flap deflected alone to $-5°$ and
  then spoiler projecting 0.05c for every 10° of
  flap deflection. Flap deflecting upward.
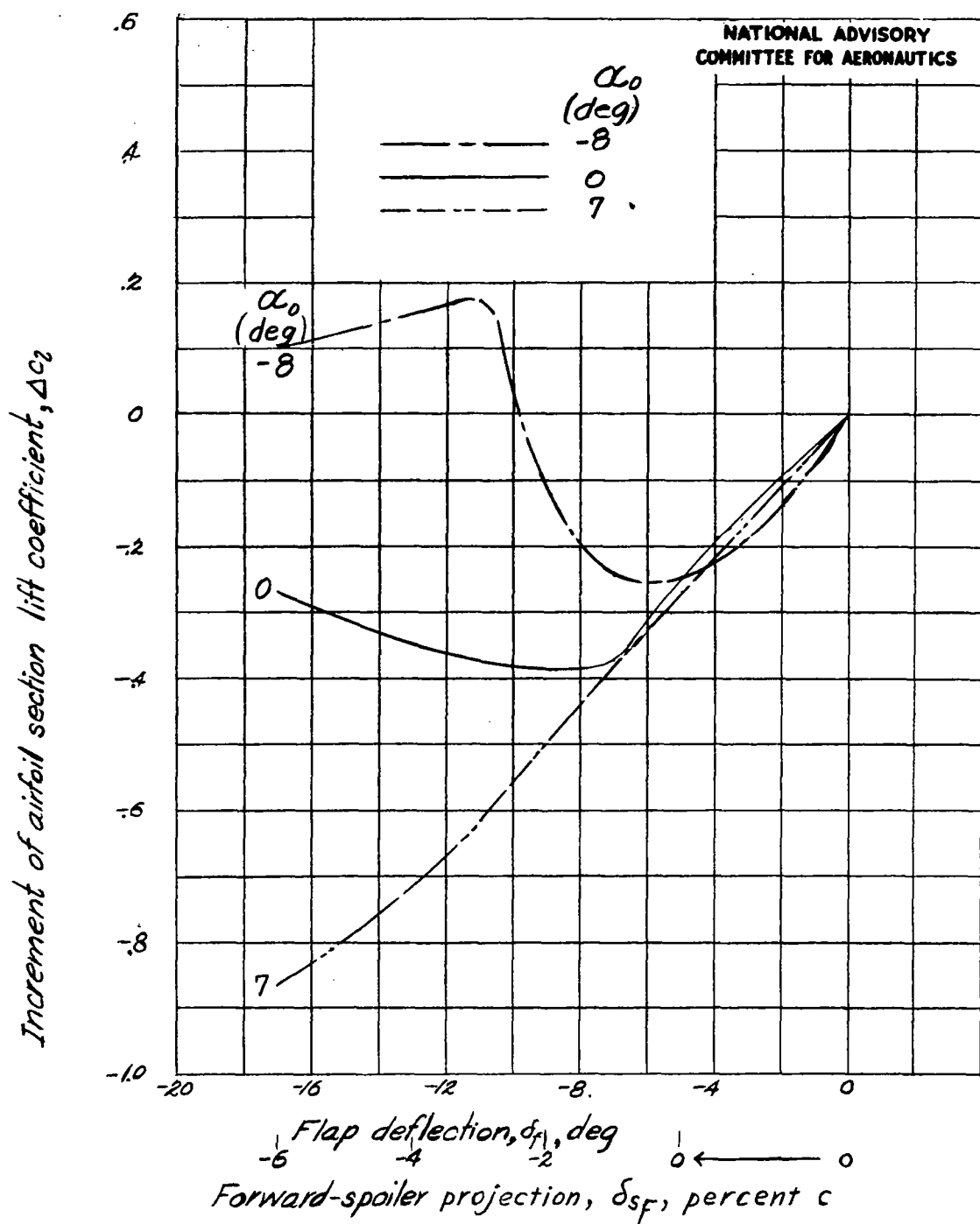
(b) Spoiler on lower surface.
Figure 22.- Concluded.
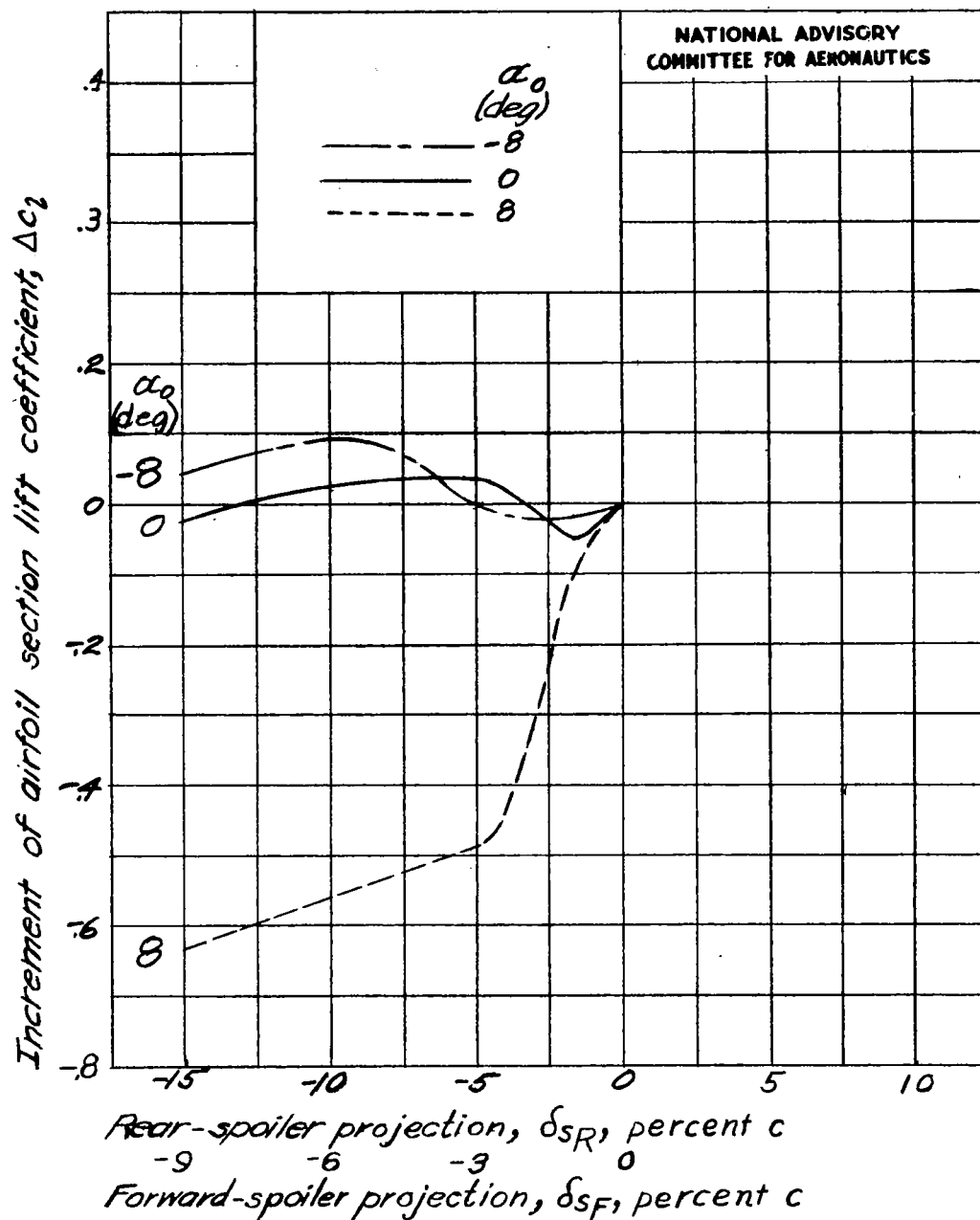
Figure 23.-Effect of a combination of forward and rear spoilers on upper surface. Forward-spoiler projection equals three-fifths rear-spoiler projection.

Fig. 24   NACA ARR No. L5F28
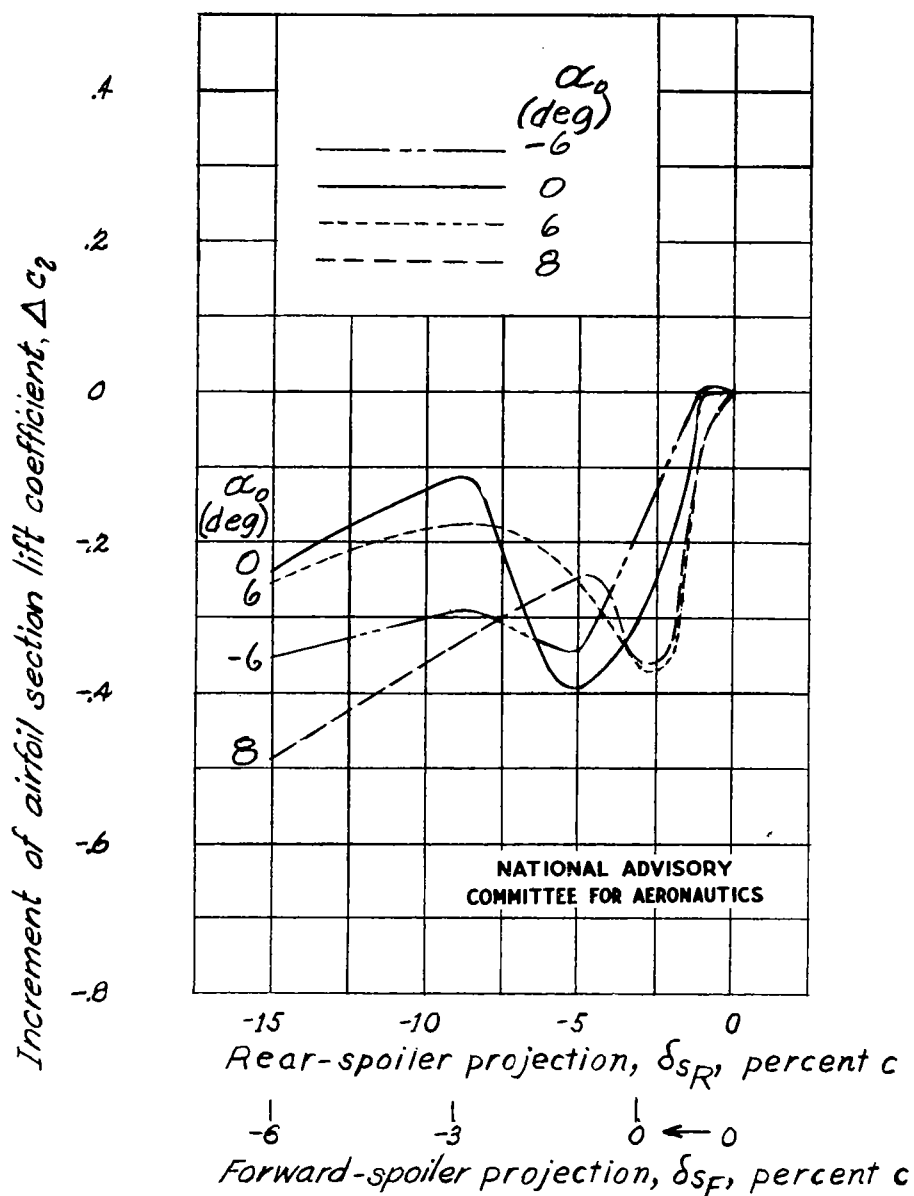
Figure 24.- Effect of a combination of spoilers, both forward and rear spoilers on upper surface with movements as follows: rear spoiler alone to 0.03c; forward spoiler then projecting one-half as fast as rear spoiler.
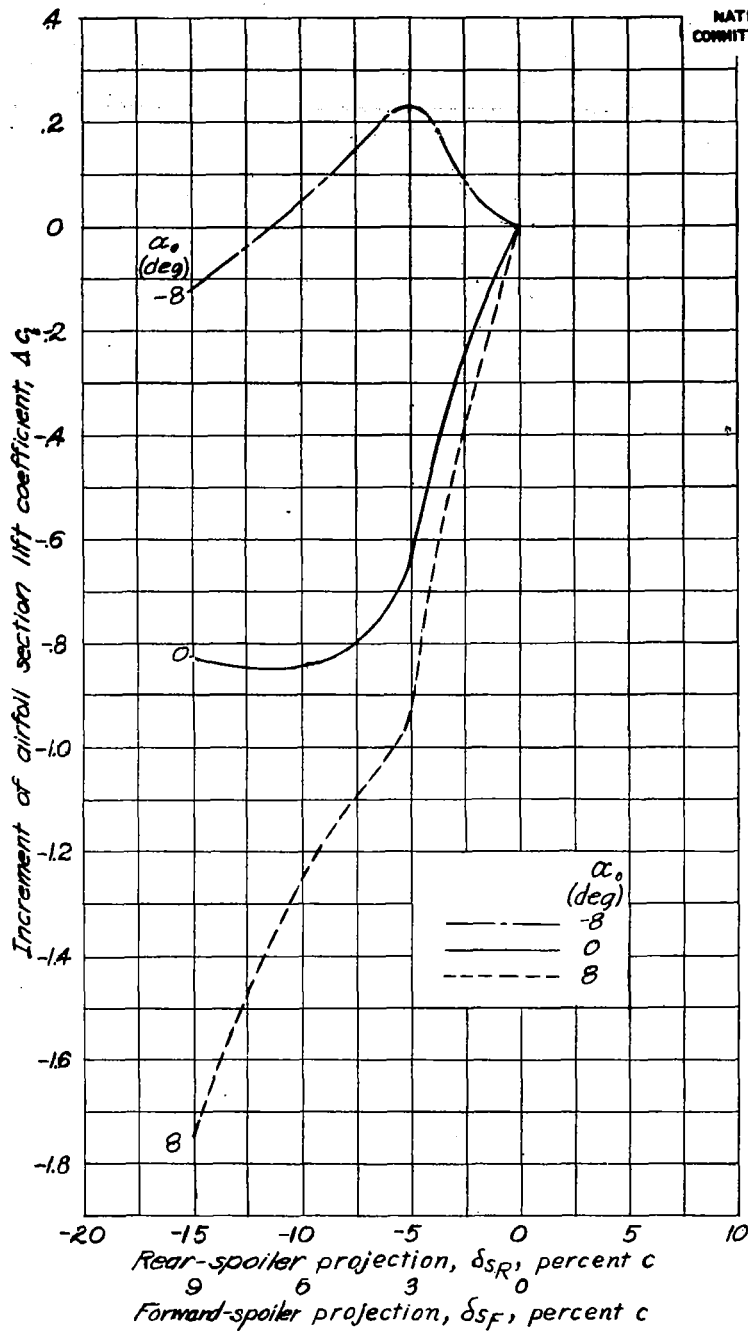
Figure 25.- Effect of a combination of spoilers. Forward-spoiler projection
always equal to three-fifths rear-spoiler projection;
rear spoiler on upper surface; forward spoiler on lower surface.

Fig. 26   NACA ARR No. L5F28
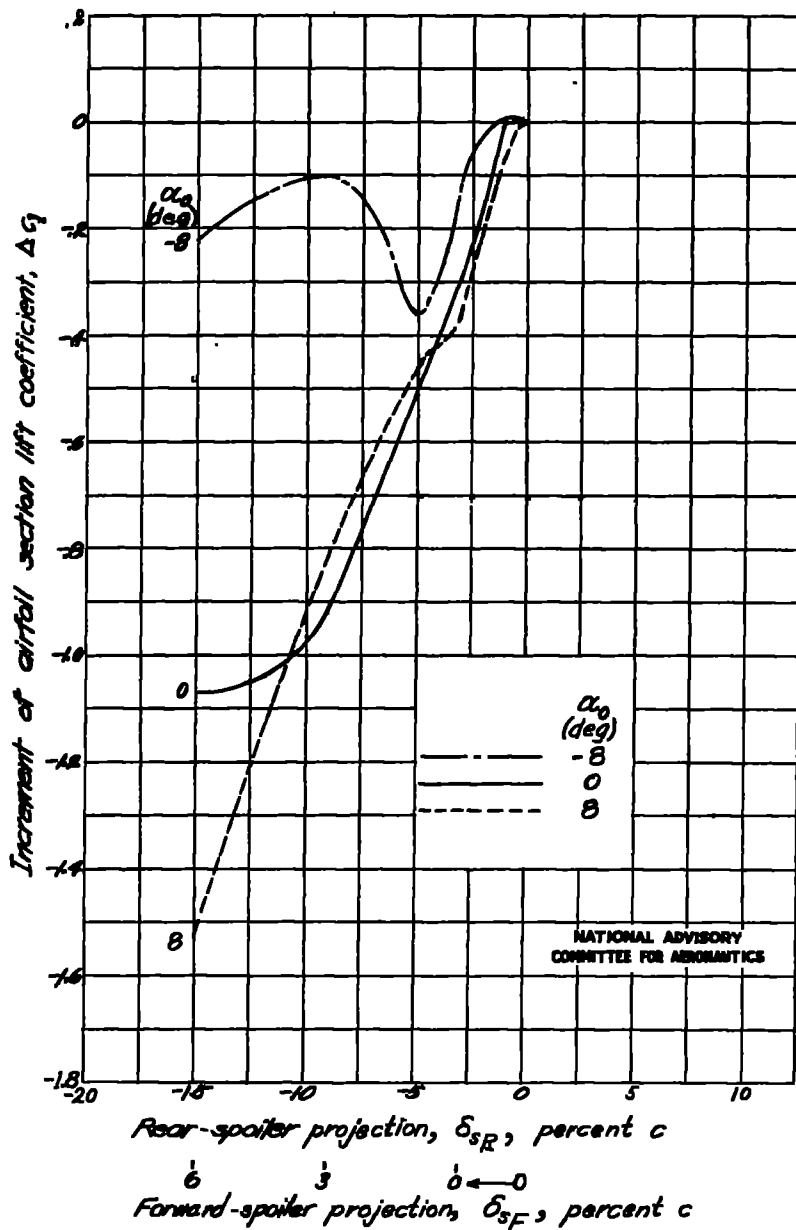
Figure 26.-Effect of a combination of spoilers. Rear spoiler on upper surface; forward spoiler on lower surface with following movements: rear spoiler alone to -0.03c; forward spoiler then projecting one-half as fast as rear spoiler.
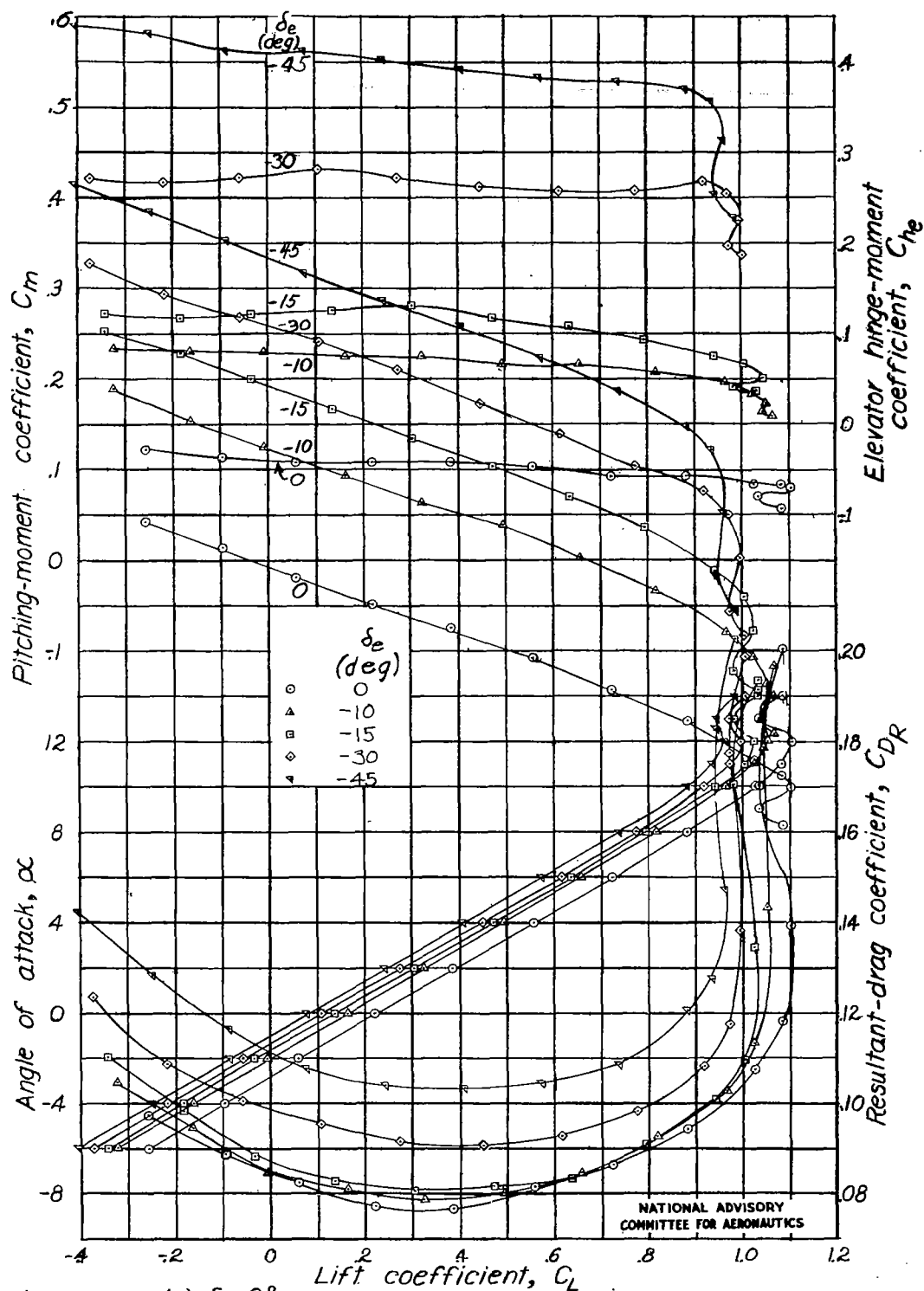
(a) $\delta_f = 0°$.

Figure 27.-Effect of elevator deflection on aerodynamic characteristics of model A near ground board.
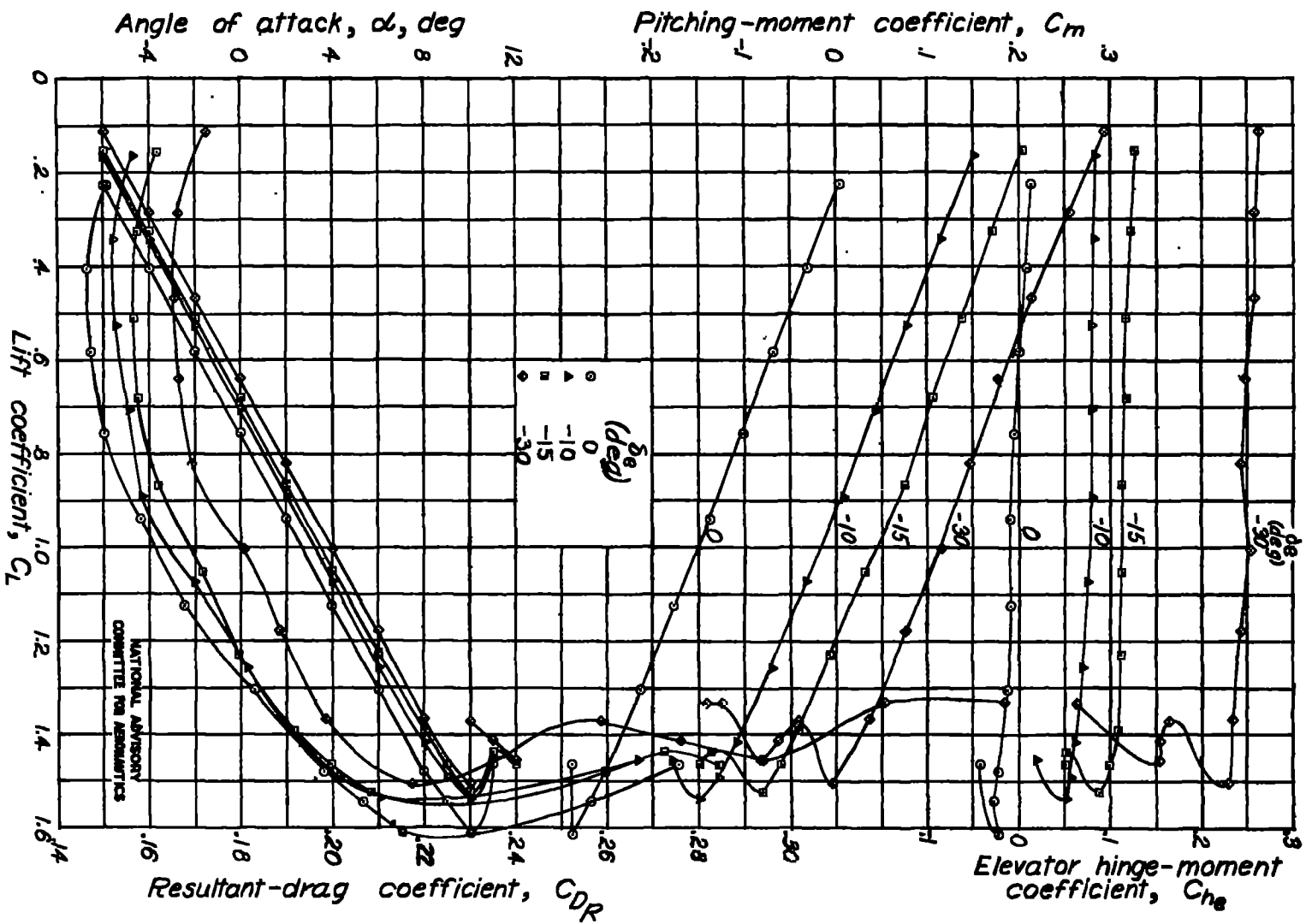
(b) δ_f = 45°.

Figure 27.- Concluded.

(a) $\delta_f = 0°$.
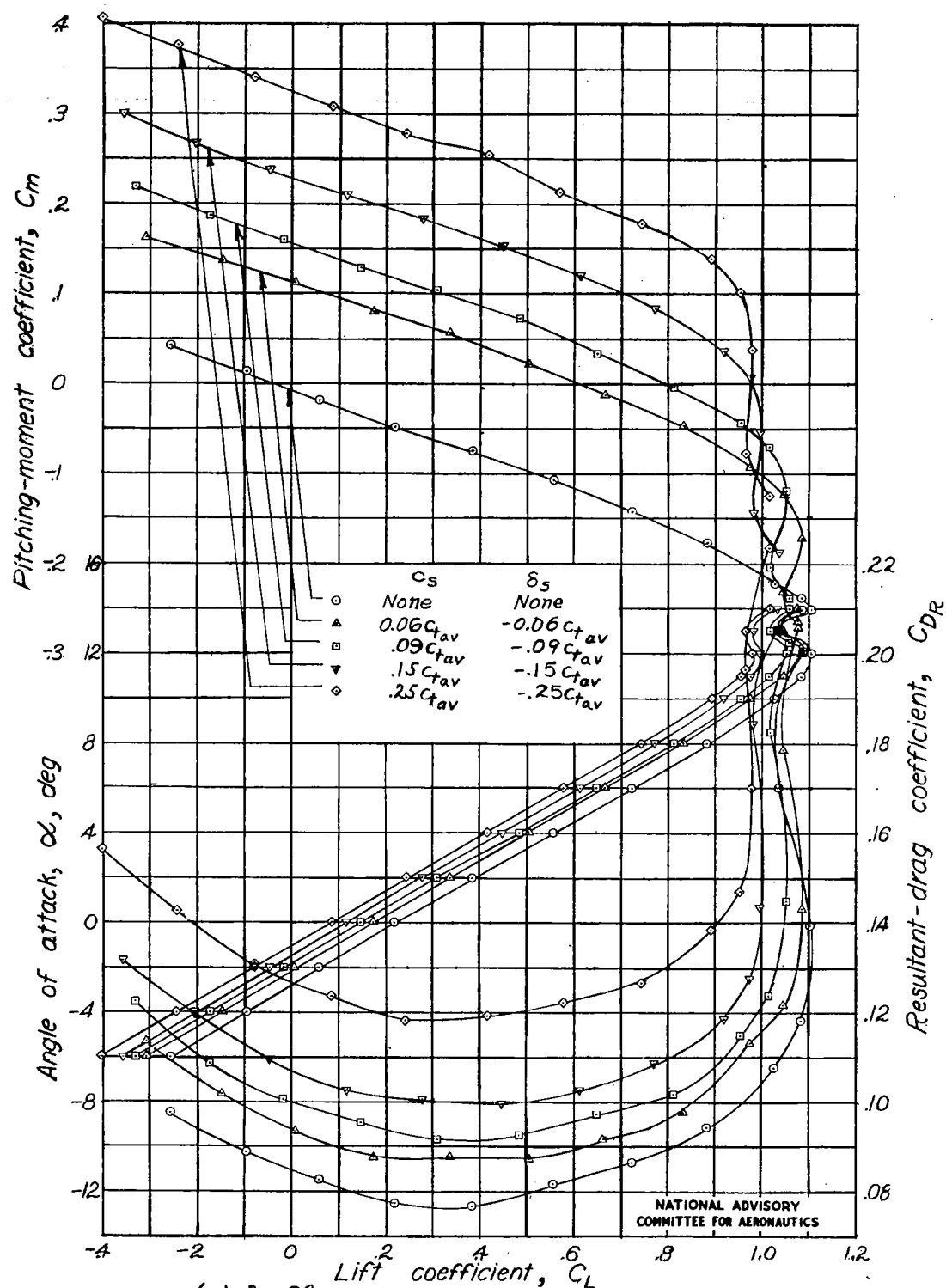
Figure 28.- Effect of spoiler projection on aerodynamic characteristics of model A near ground board. $\delta_e = 0°$. Spoiler at hinge line on upper surface.
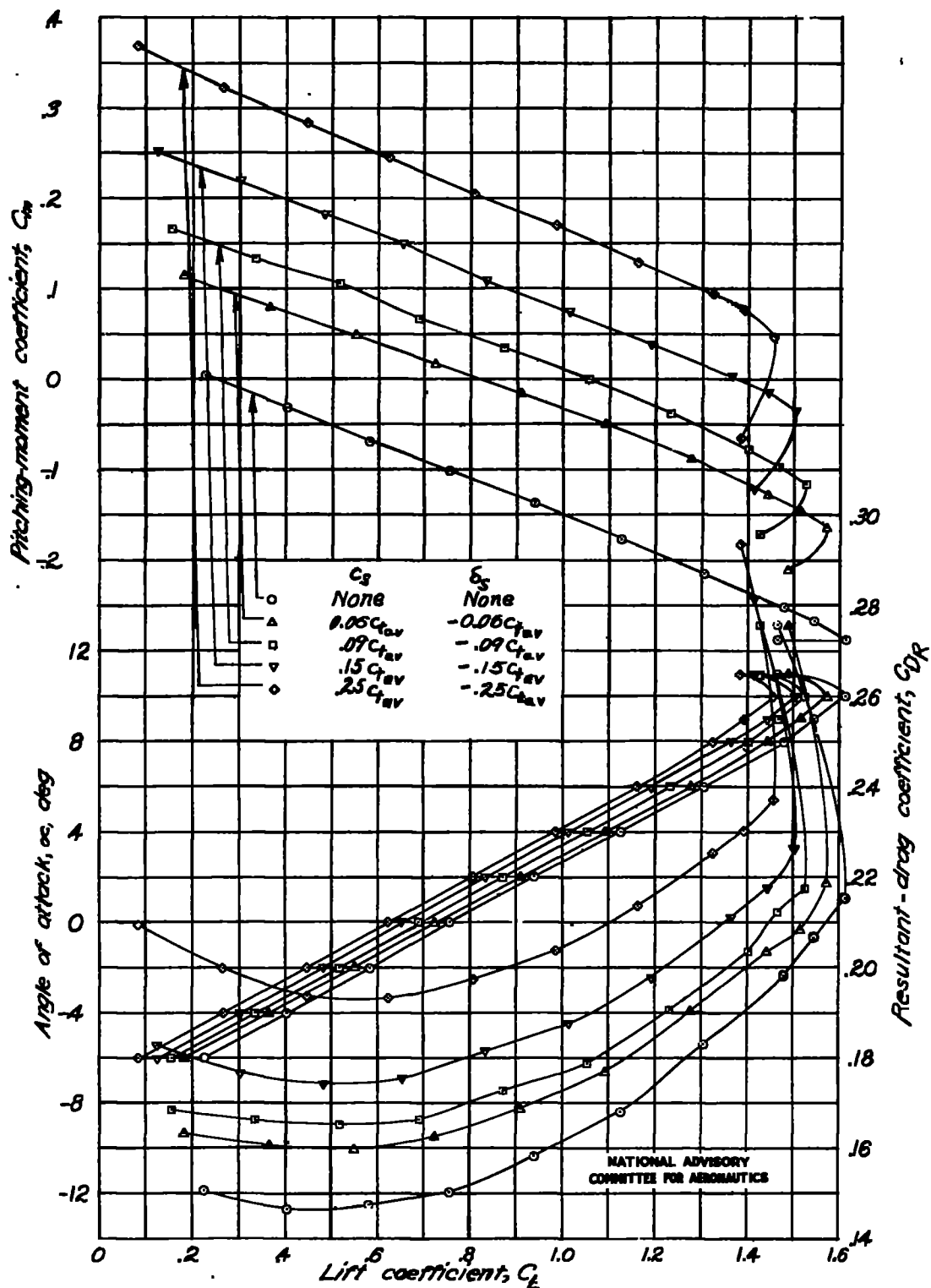
(b) $\delta_f = 45°$.
Figure 28.- Concluded.
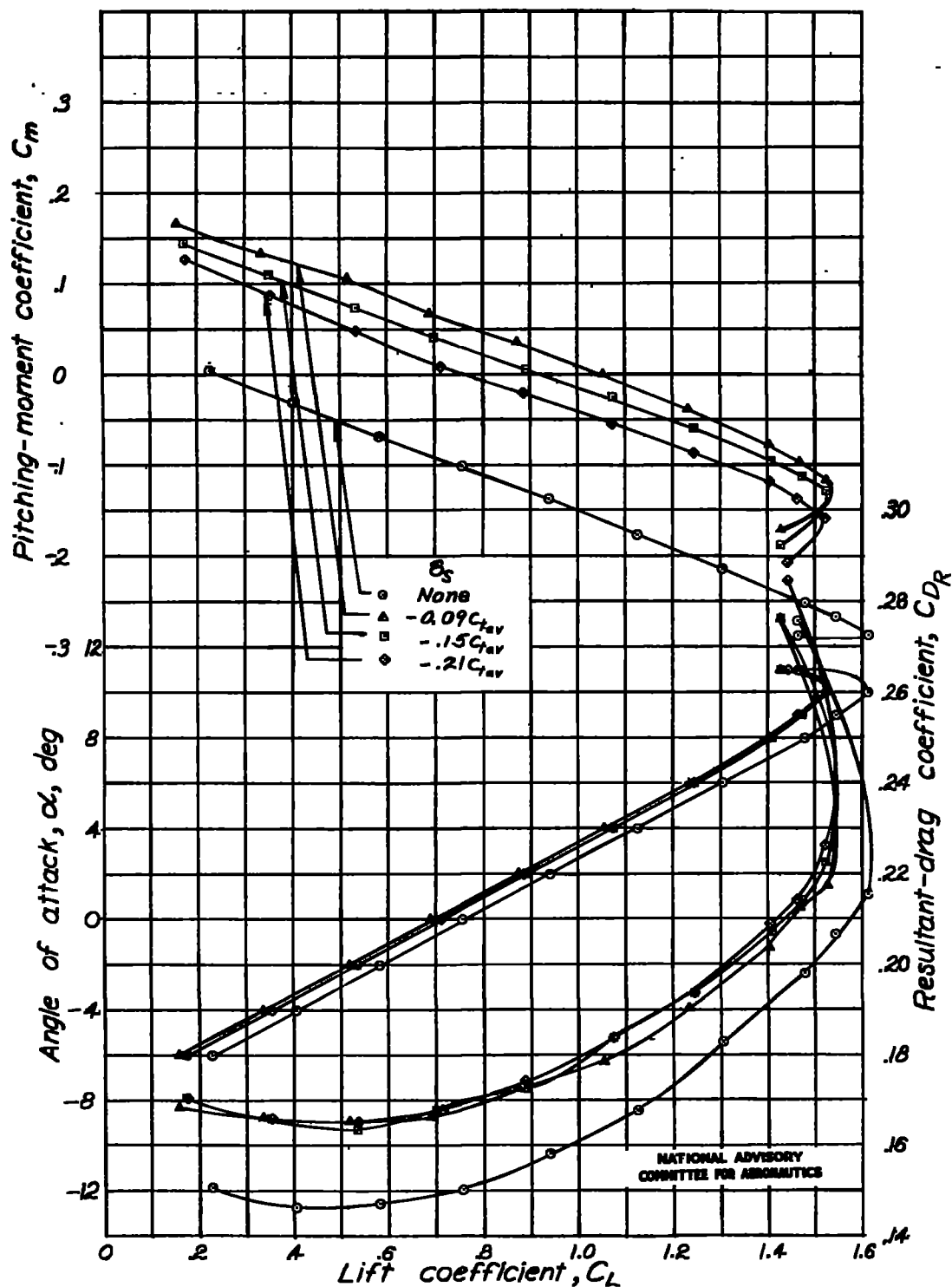
Figure 29.- Effect of spoiler gap on the aerodynamic characteristics of model A near ground board. $c_s = 0.09c_{t_{av}}$; $\delta_f = 45°$; $\delta_e = 0°$; spoiler at hinge line on upper surface.

Fig. 30   NACA ARR No. L5F28
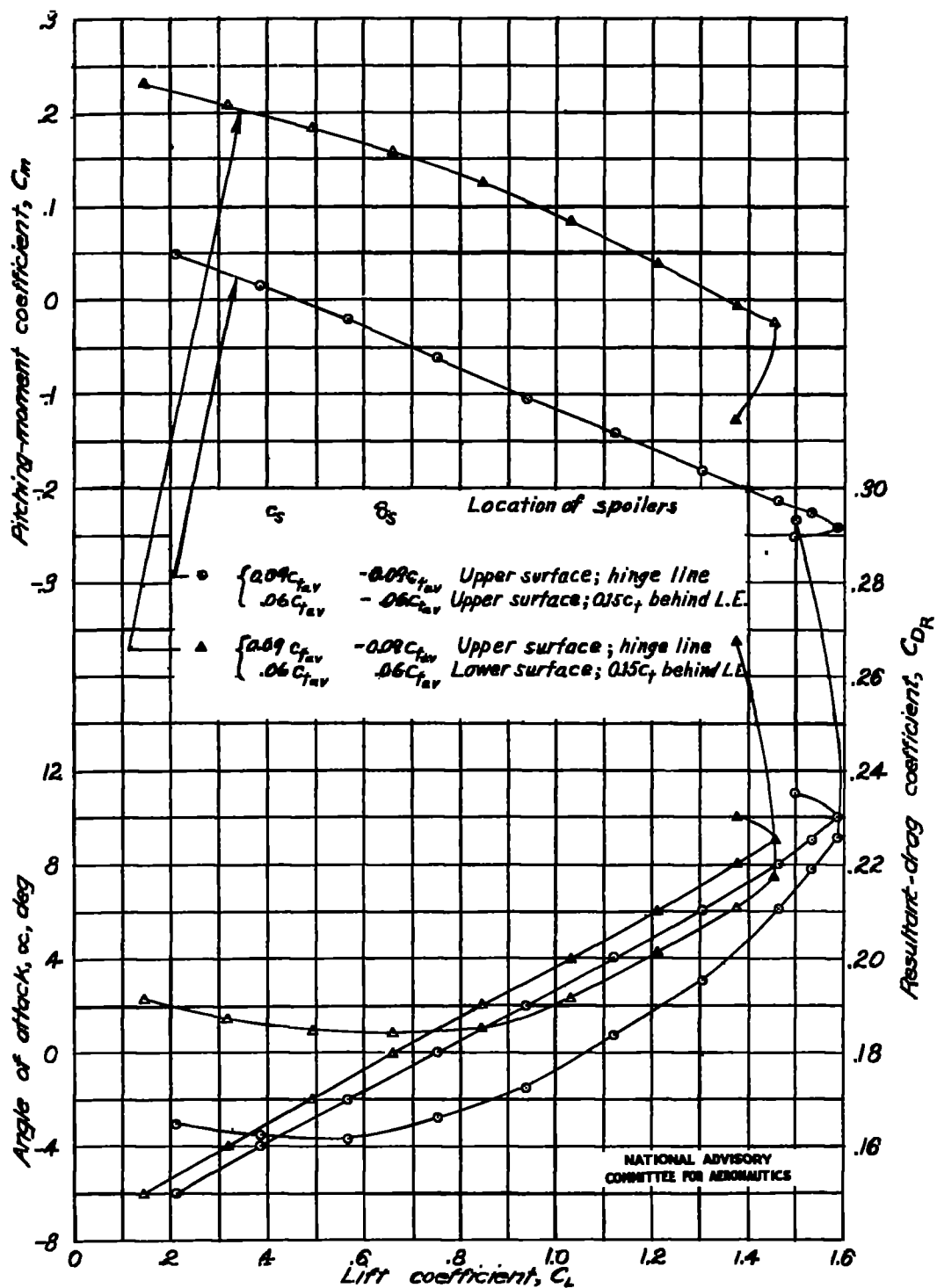
Figure 30.- Effect of spoiler combinations on aerodynamic characteristics of model A near ground board. $\delta_f = 45°$; $\delta_e = 0°$.
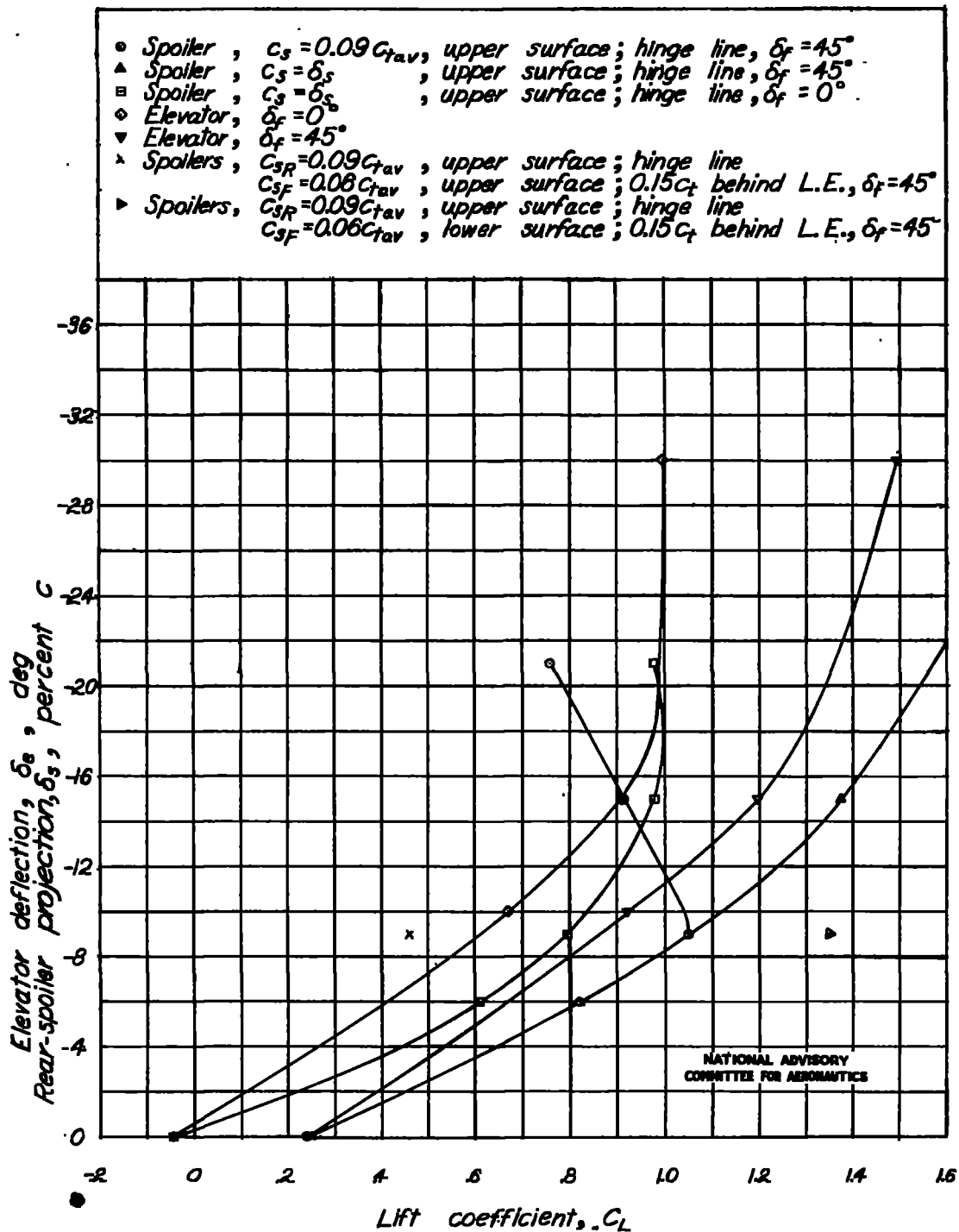
Figure 31.- Elevator deflections and spoiler projections required to trim model A near ground board.
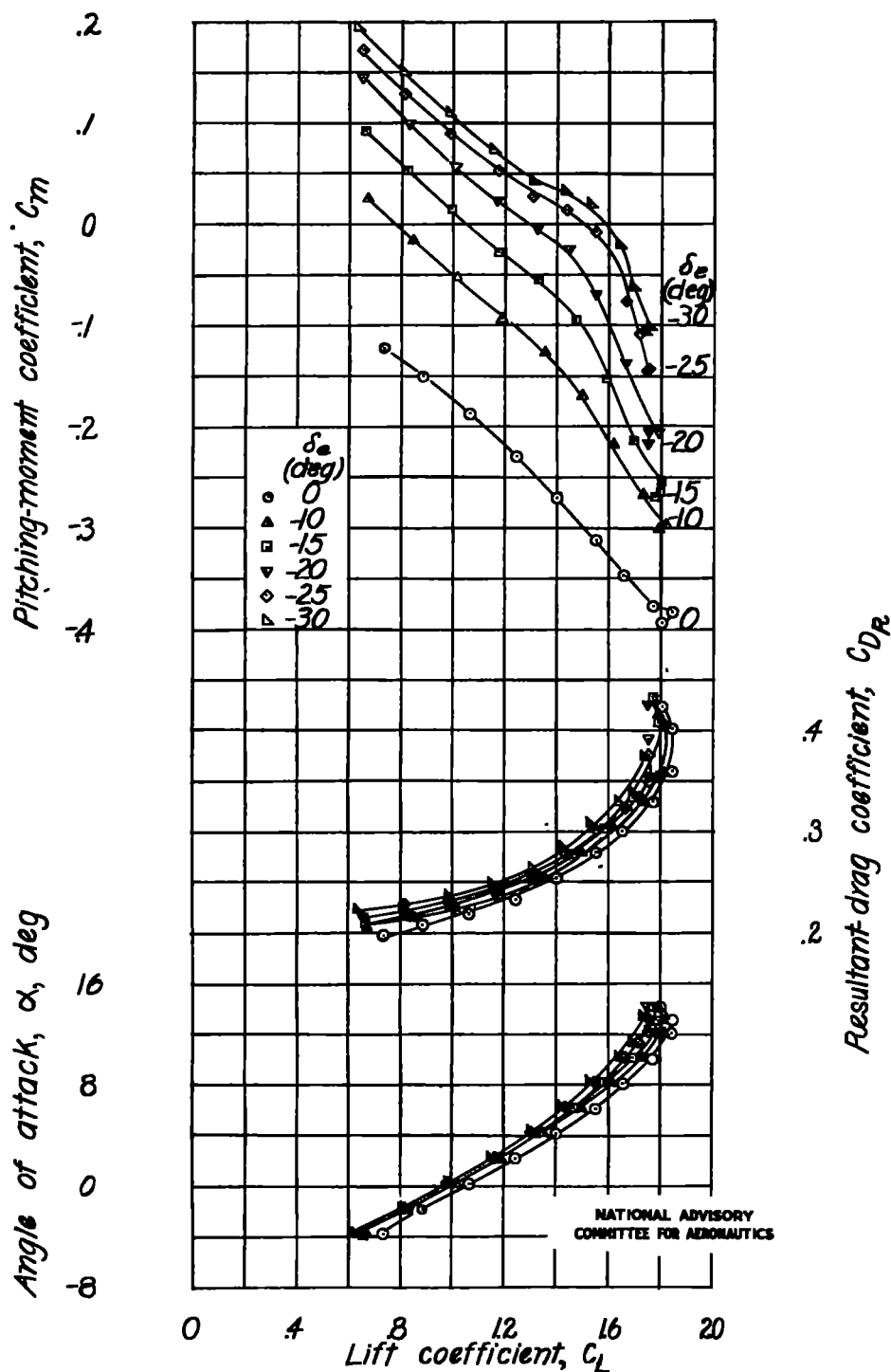
(a) No spoiler.

Figure 32.- Effects of elevator deflection and spoiler projection on the aerodynamic characteristics of model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = 1.67°$; center of gravity at $0.18 c'$.
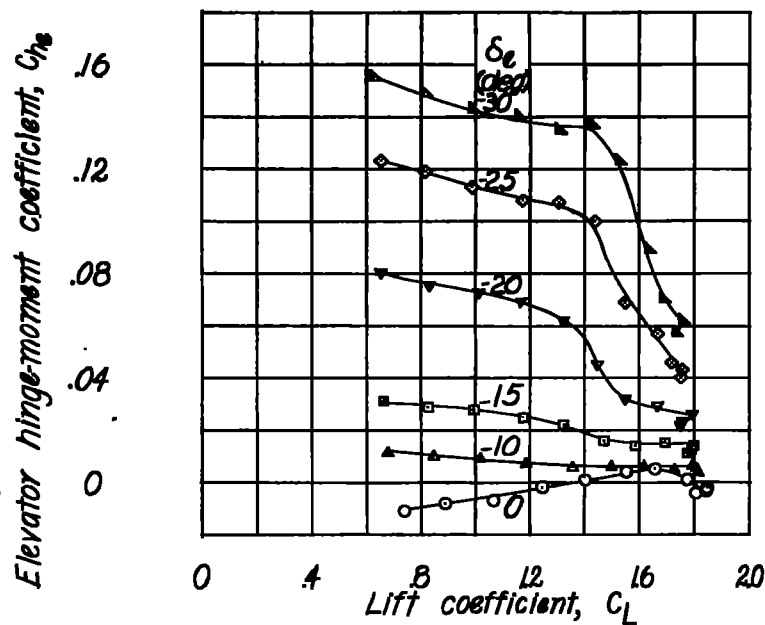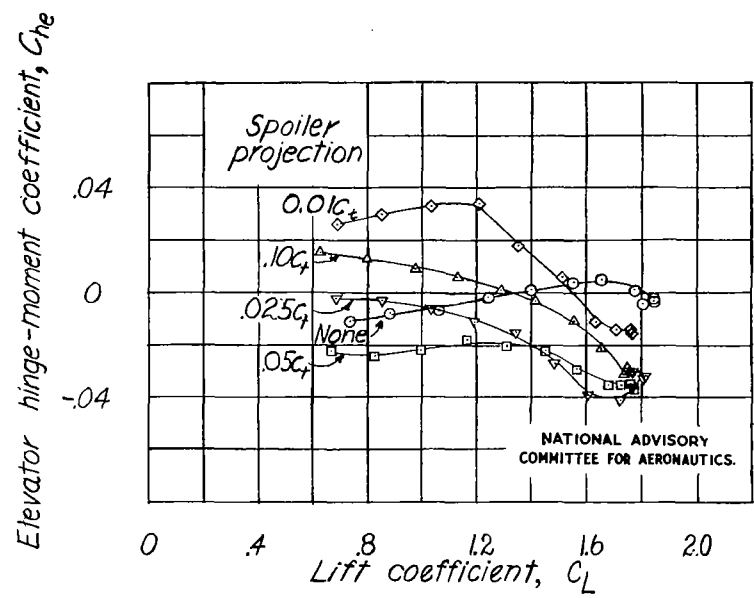
(a)   No spoiler.

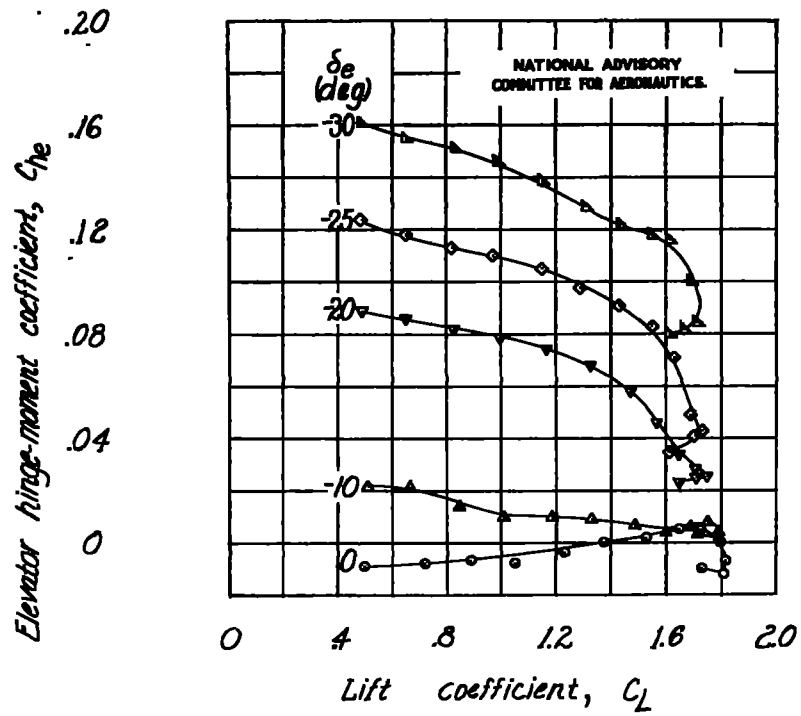Figure 32.- Continued.
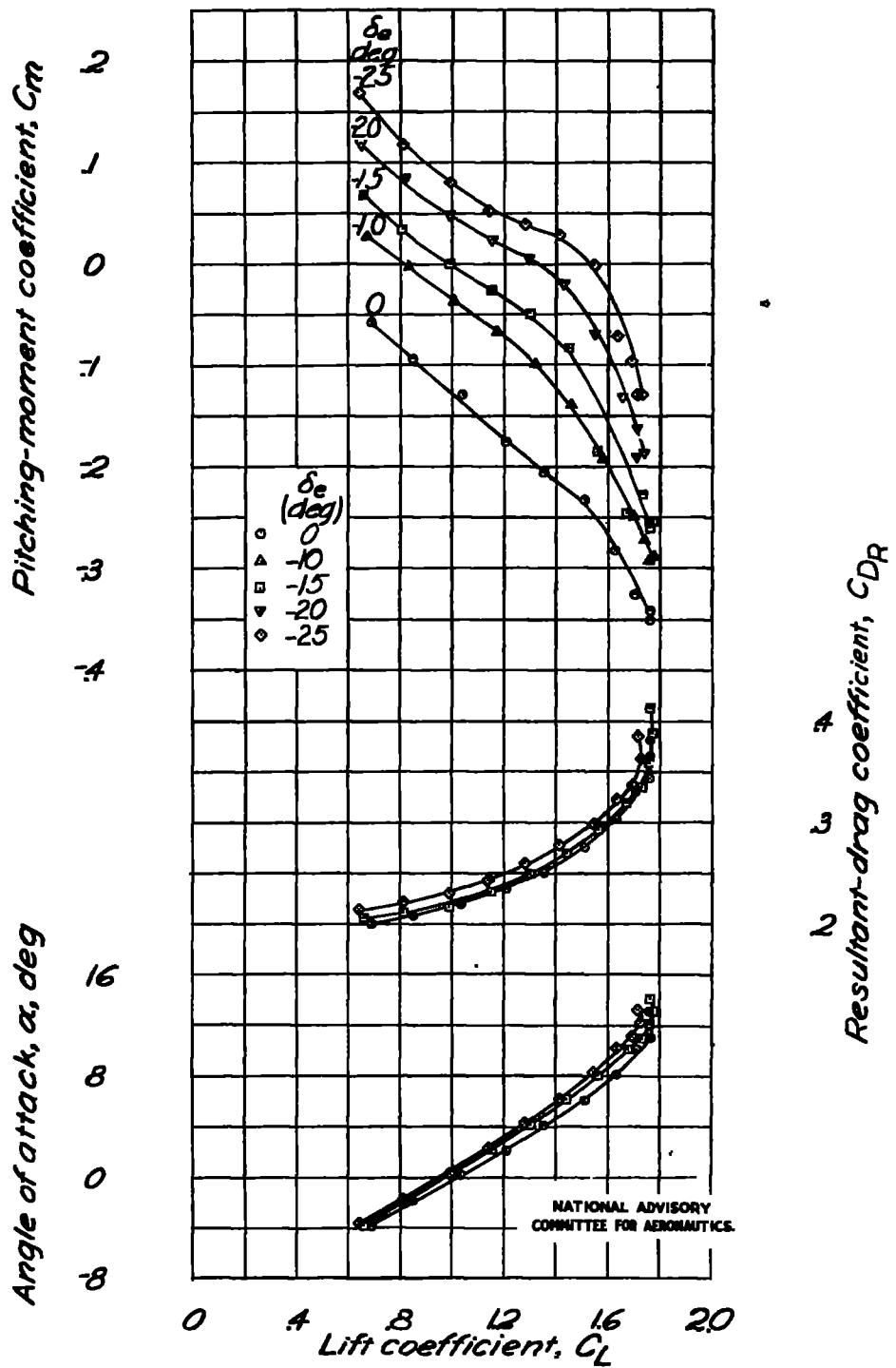
(b) 0.01c_t spoiler.

Figure 32.- Continued.
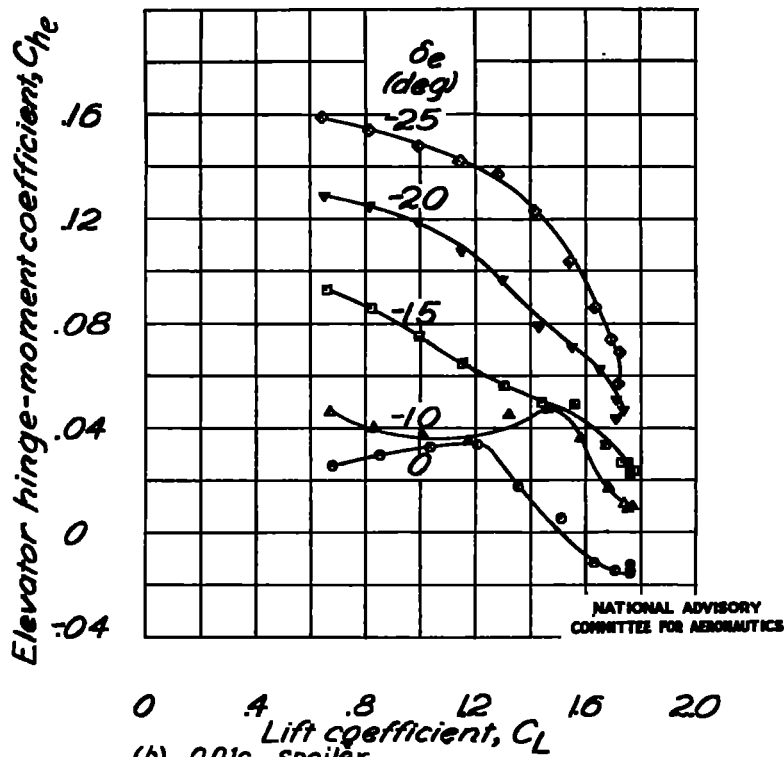
(b) 0.01c, spoiler.

Figure 32.- Continued.

(c) 0.025c_t spoiler.

Figure 32.- Continued.
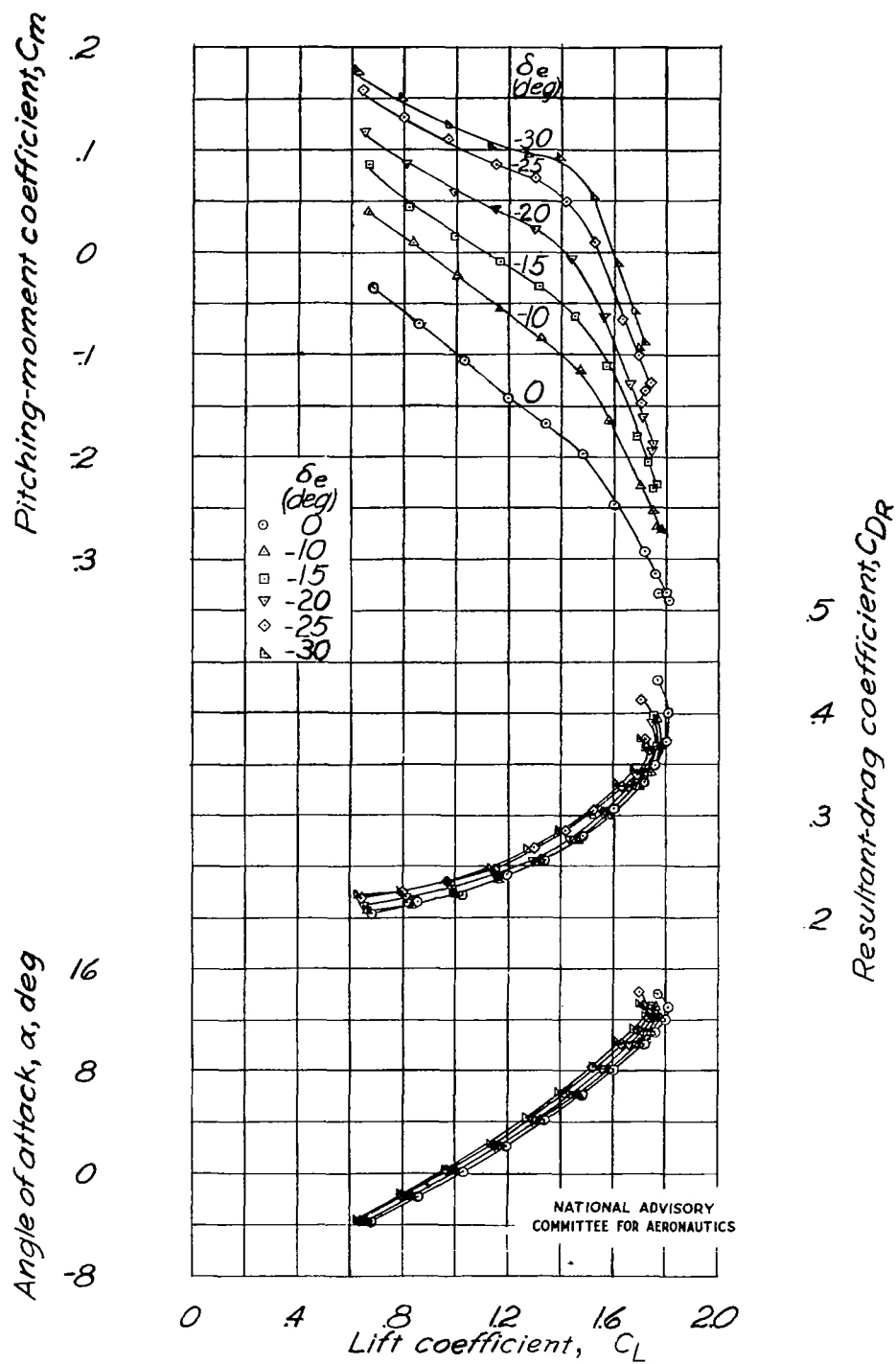
(C) 0.025c_t spoiler.

Figure 32.-Continued.
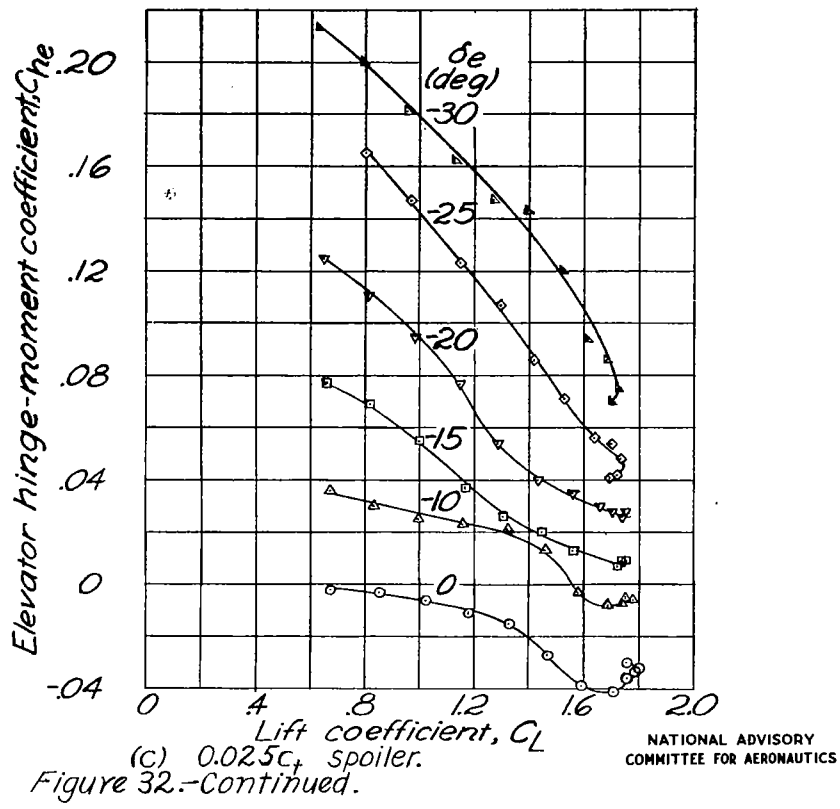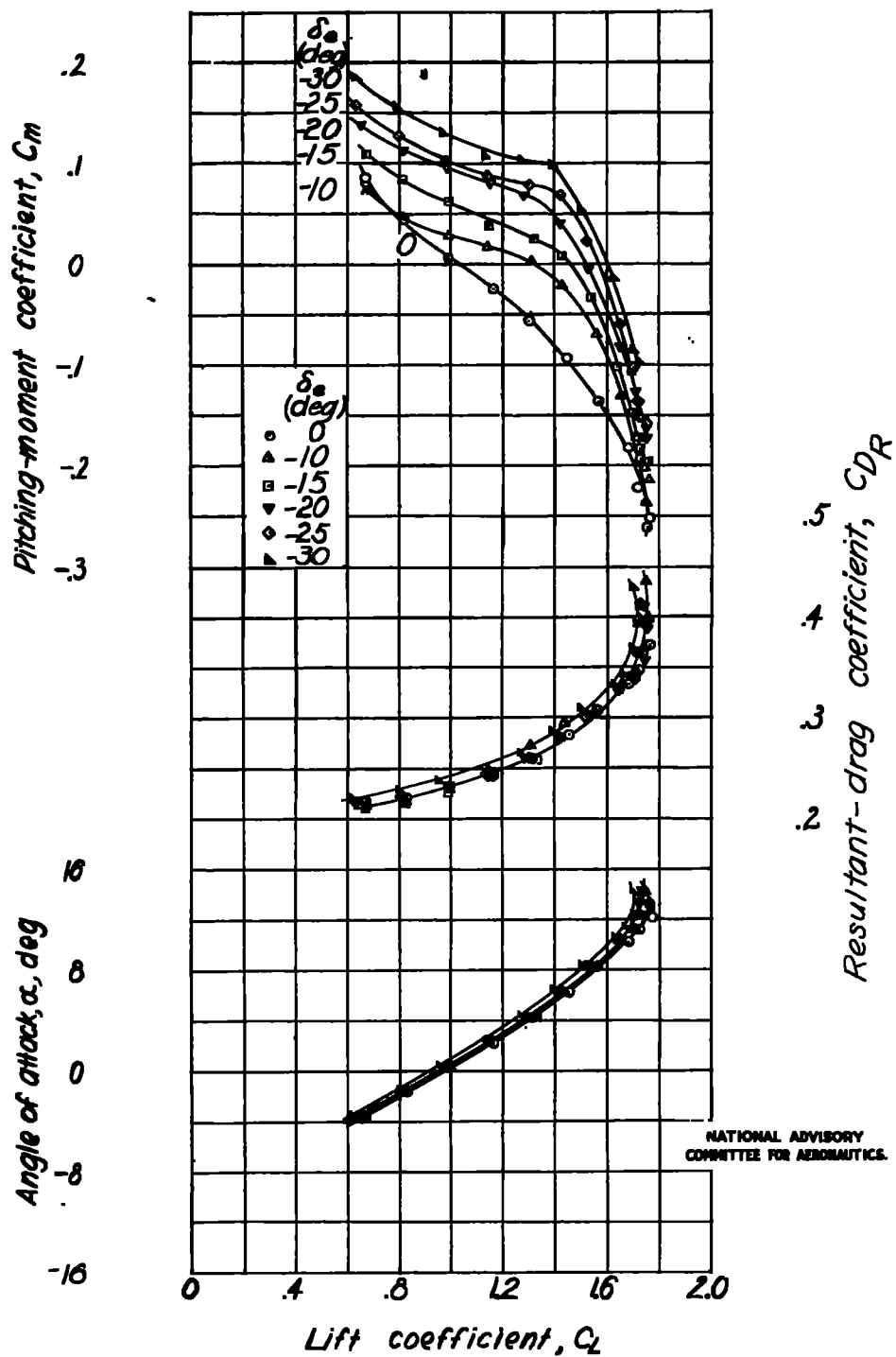
(d) 0.05c_t spoiler.

Figure 32.- Continued.

(d) 0.05c_f spoiler.

Figure 32.–Continued.

Fig. 33   NACA ARR No. L5F28
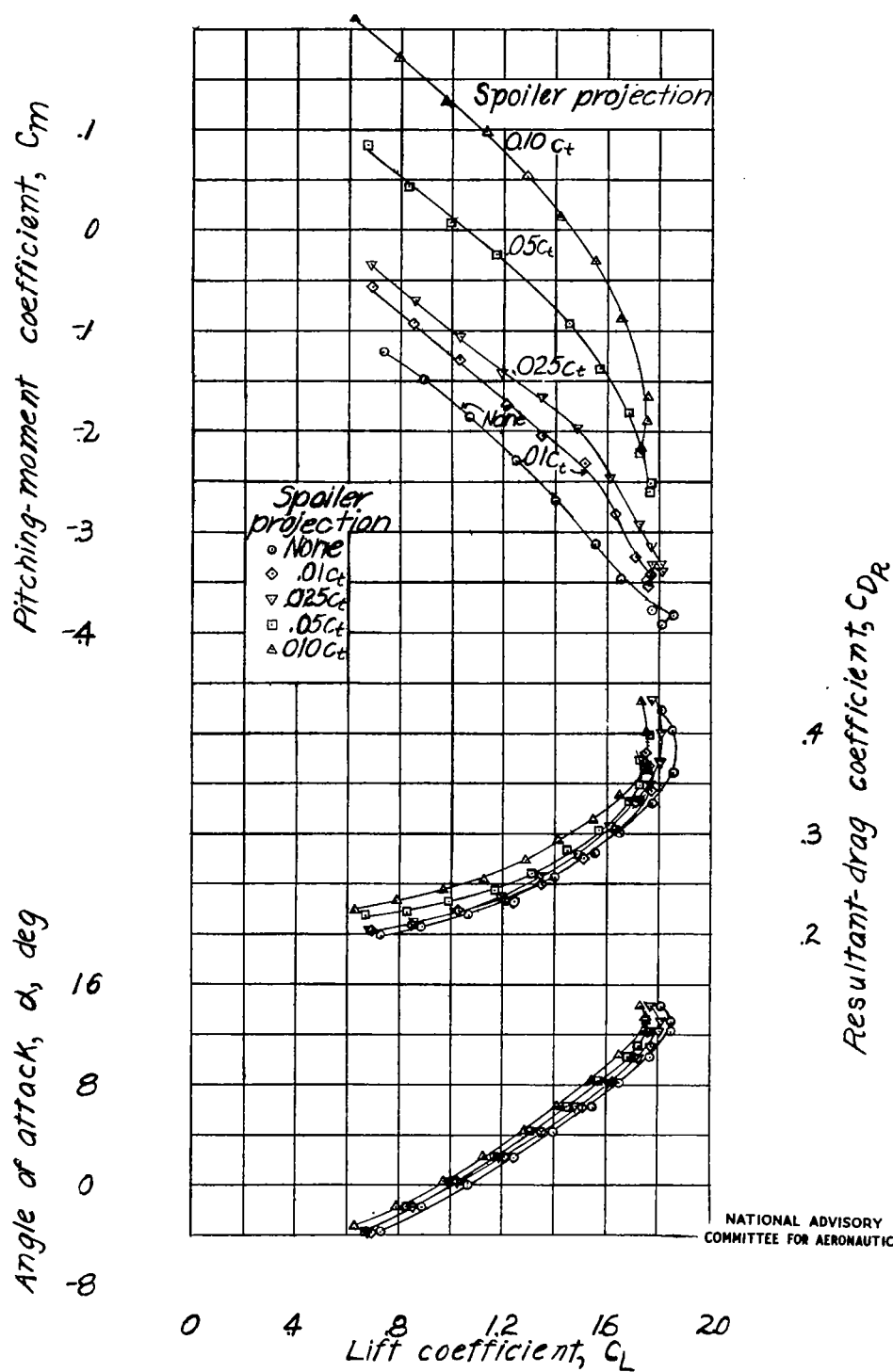
Figure 33.— Effect of spoiler projection on the aerodynamic characteristics of model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = 1.67°$; $\delta_e = 0°$; center of gravity at $0.18c'$.

Figure 33.– Concluded.
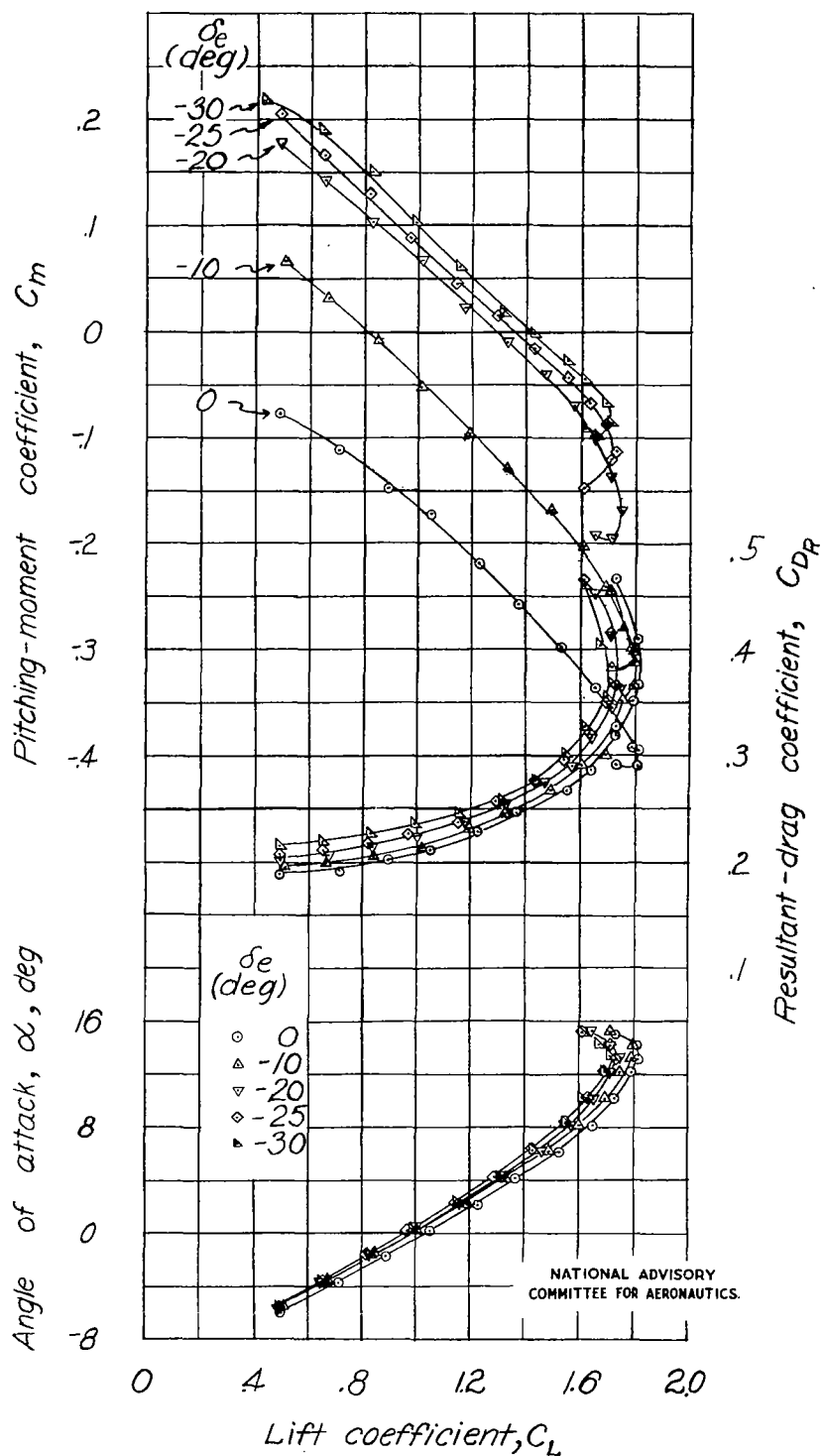
(a) No spoiler ; $i_t = 1.00°$.
Figure 34.- Effect of elevator deflection on the aerodynamic
characteristics of model B near ground. Propeller
windmilling; landing configuration; horizontal tail raised
4.0 inches; center of gravity at 0.18 c'.

(a) No spoiler; $i_t = 1.00°$.
Figure 34.- Continued.
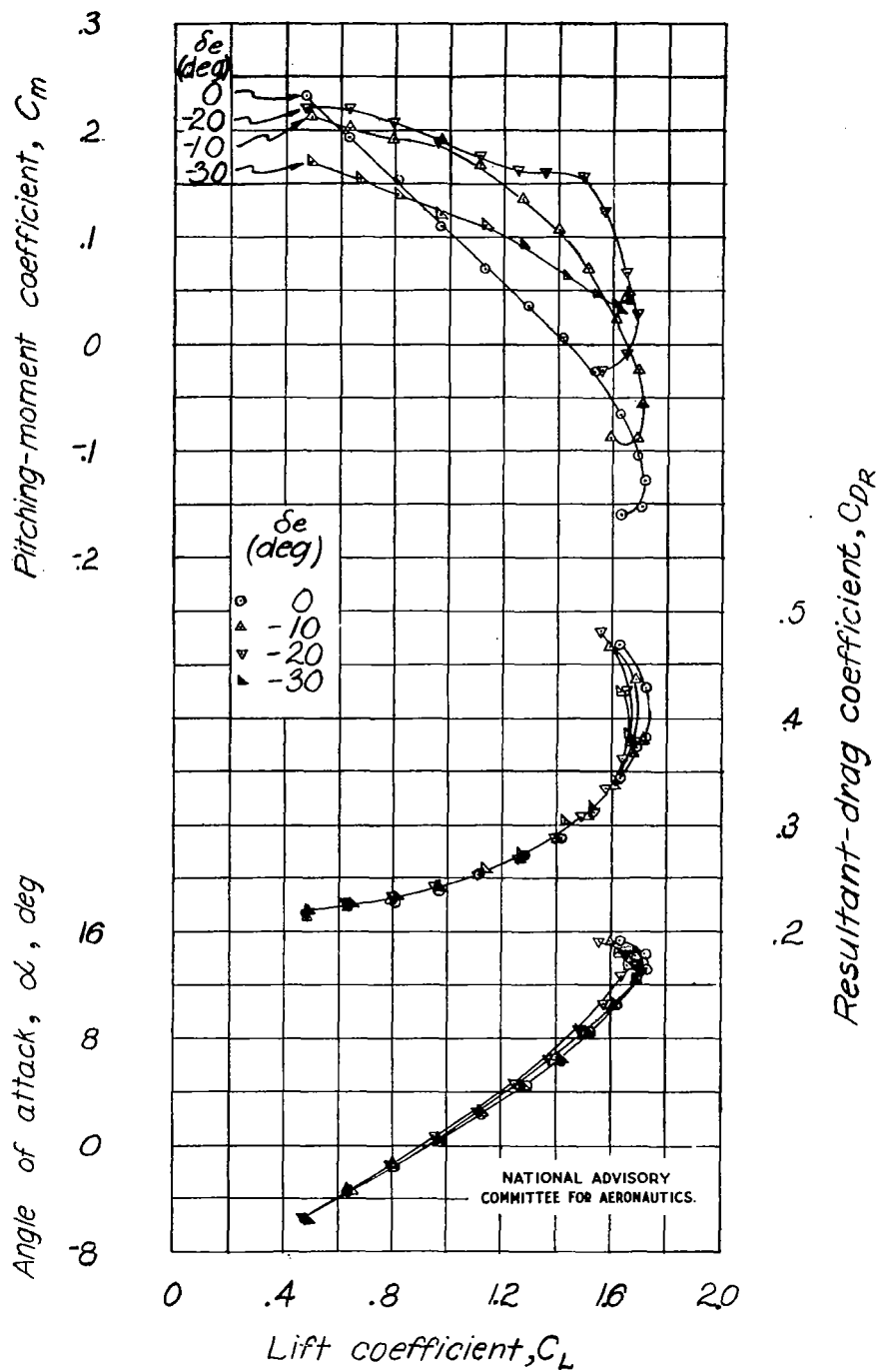
(b) $0.10c_t$ spoiler; $i_t = 1.10°$.

Figure 34.– Continued.

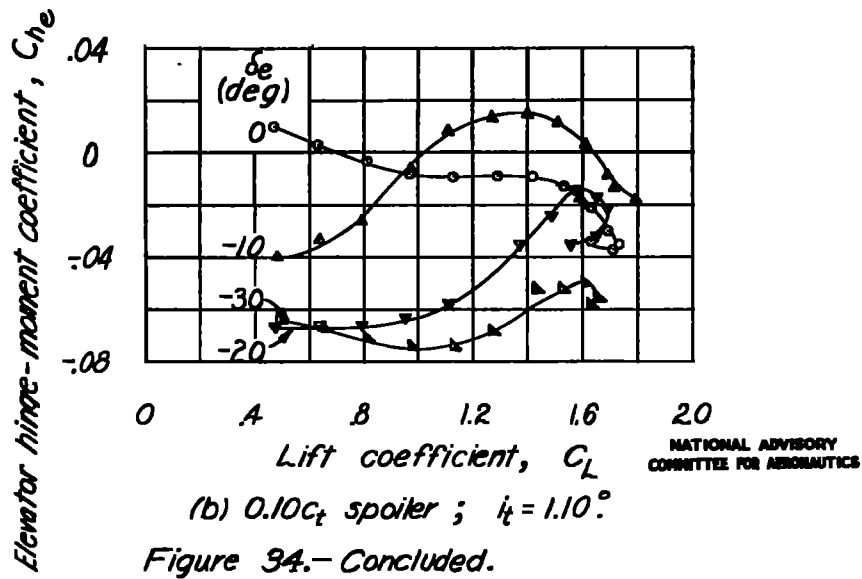(b) 0.10c_t spoiler ; $i_t = 1.10°$.

Figure 34.— Concluded.

Fig. 35
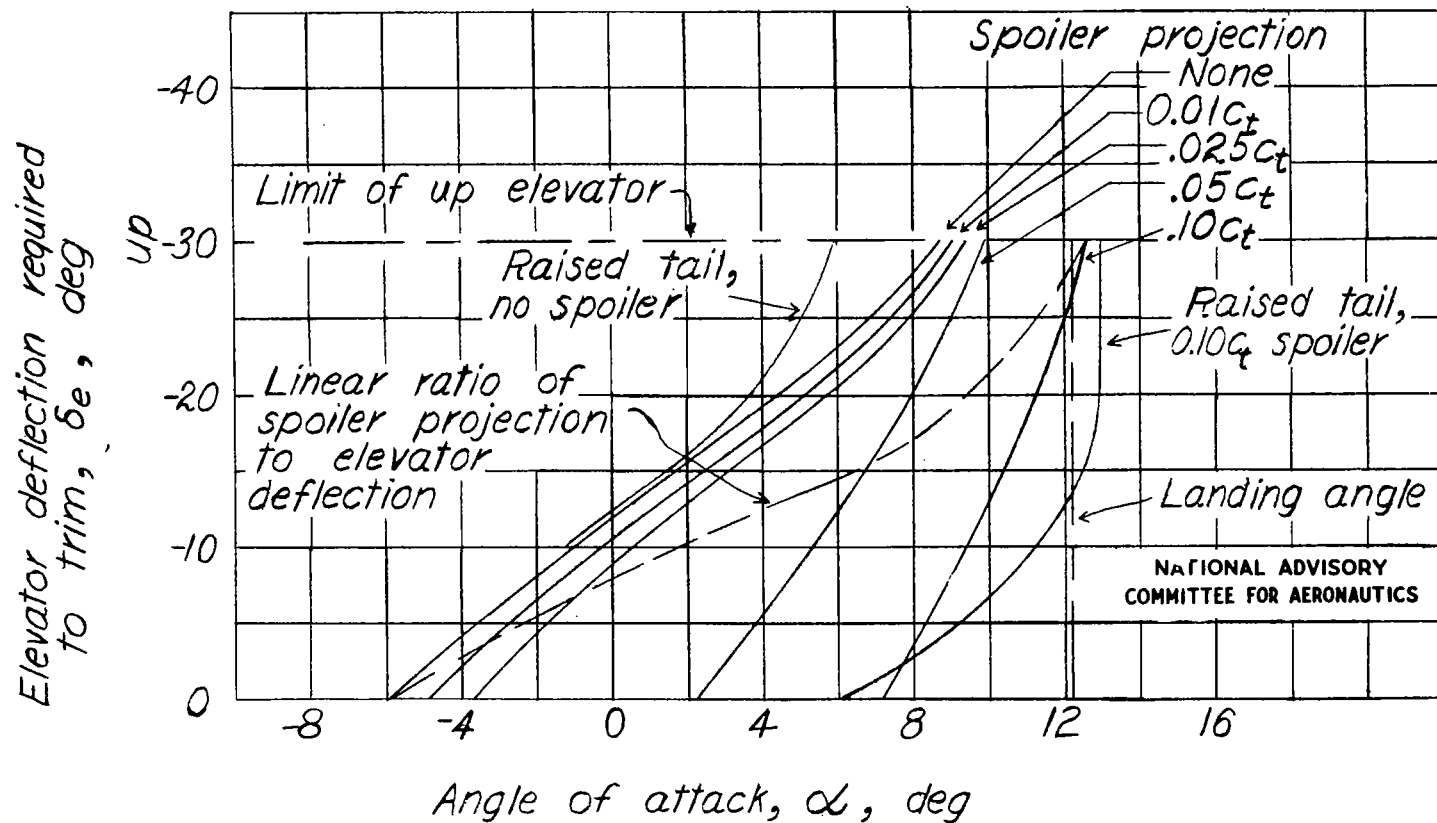
Figure 35.— Elevator deflection required to trim model B near ground. Propeller windmilling; landing configuration; $i_t = -1.42°$; forward center of gravity at 14.2 percent c'.
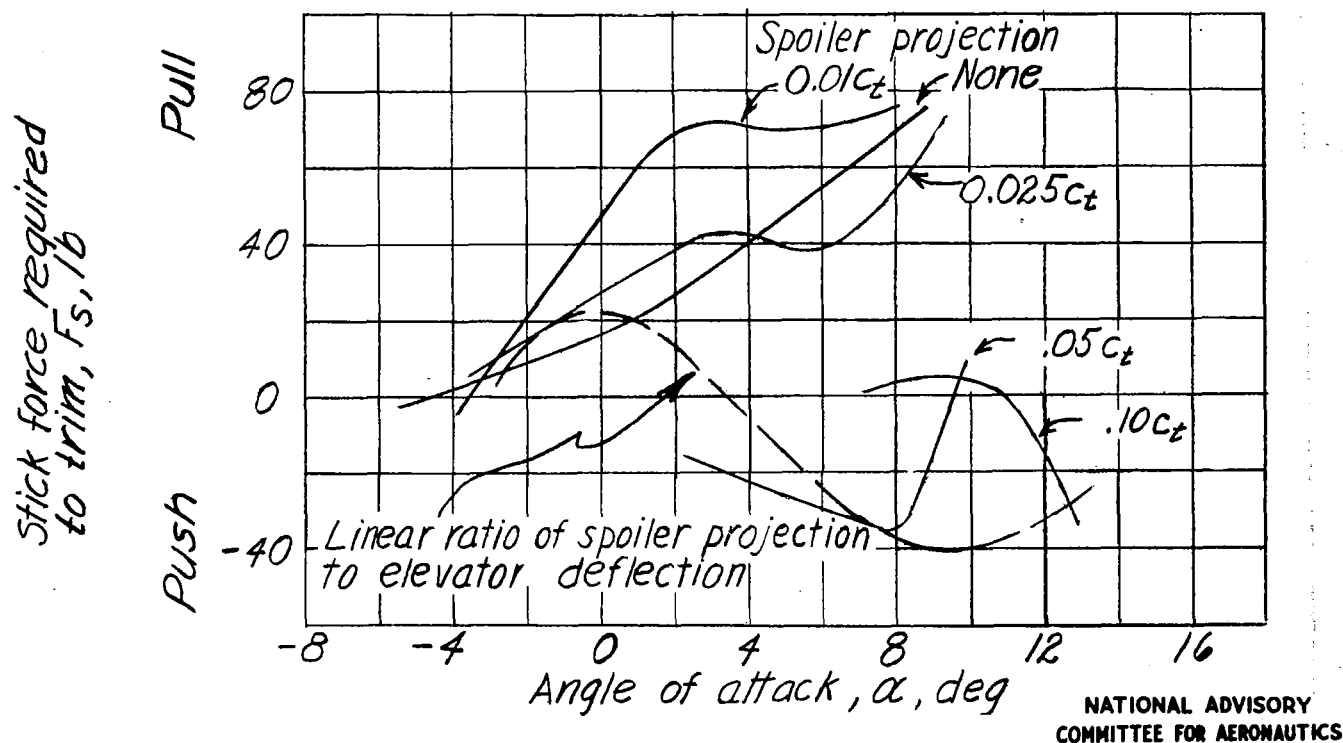
Figure 36.- Effect of spoiler projection on stick force required to trim model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = -1.42°$; forward center of gravity at 14.2 percent c'.
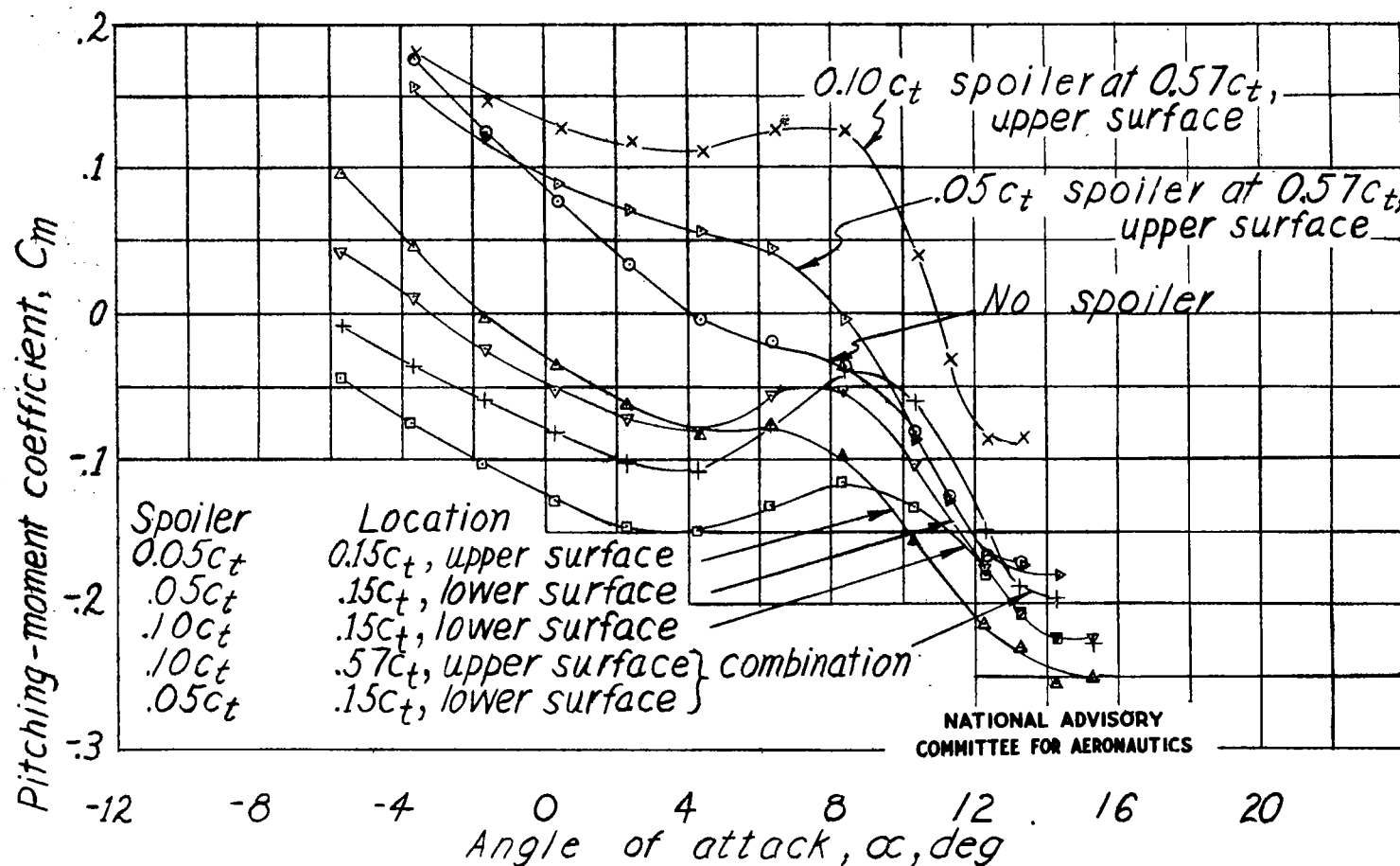
Fig. 36

Fig. 37

Figure 37.– Effect of spoiler height and location on the pitching-moment coefficient of model B near ground. Propeller windmilling; landing configuration; horizontal tail in normal location; $i_t = 1.00°$; $\delta_e = -30°$ ($\delta_e = -25°$ for $0.05c_t$ and $0.10c_t$ spoilers at $0.57c_t$, upper surface); forward center of gravity at 14.2 percent c'.
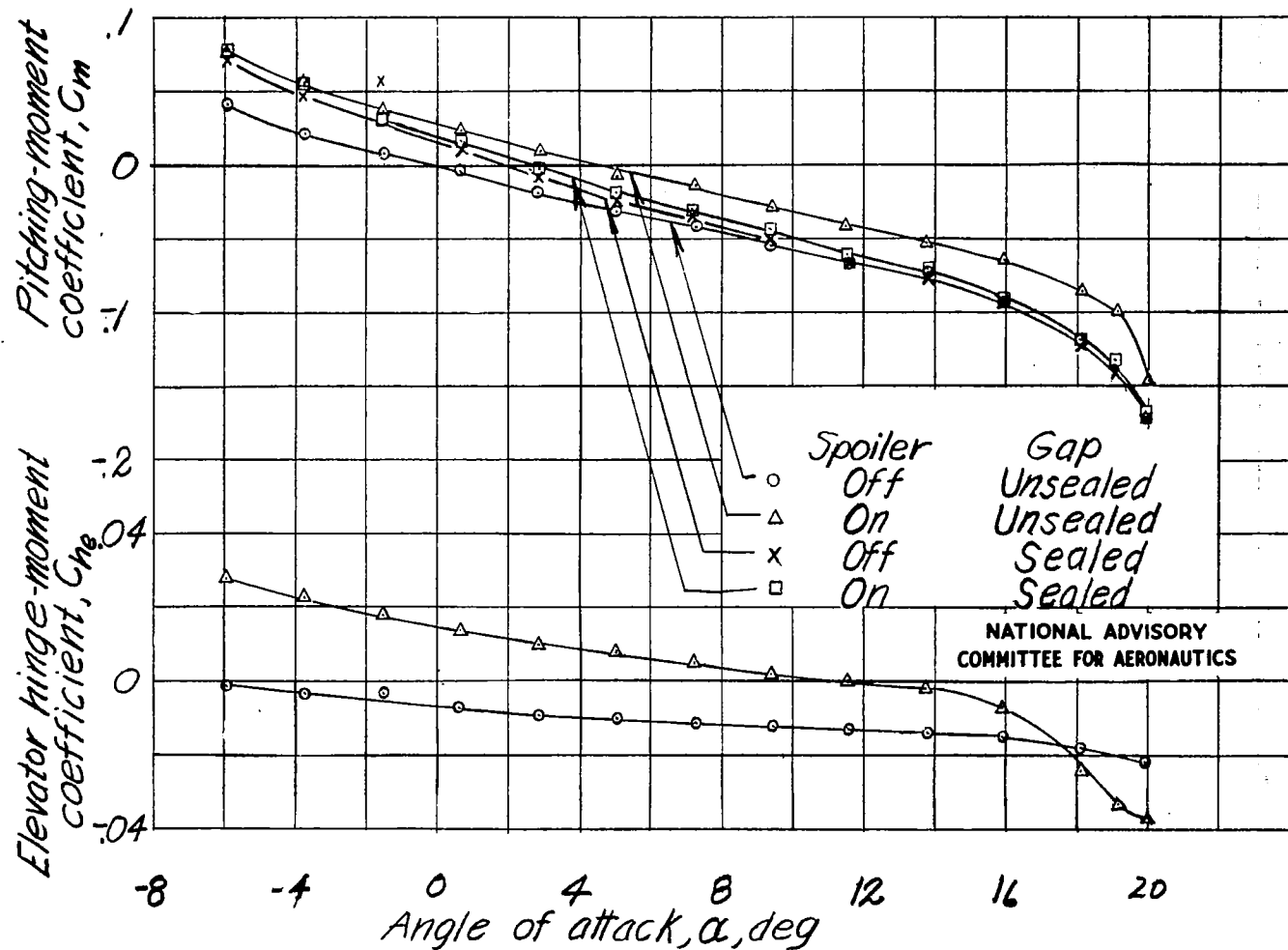
Figure 38.— Effect of $0.008c_t$ spoiler and elevator gap on the pitching-moment coefficient of a typical fighter-airplane model. $\delta_f = 40°$; $\delta_e = \Psi = 0°$.

Fig. 38